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PROGRAM ON EARTH OBSERVATION DATA MANAGEMENT SYSTEMS (EODMS)

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16. Abstract

The purpose of this report is to investigate a group of potential users of satellite remotely sensed data -- state, regional, and local agencies involved in natural resources management. We assess this group's needs in five states, (Illinois, Iowa, Minnesota, Missouri, and Wisconsin) and outline alternative data management systems to satisfy these needs. The major contributions of this work are: i) A comprehensive data needs analysis of state and local users. ii) The design of remote sensing-derivable information products that serve priority state and local data needs. iii) A cost and performance analysis of alternative processing centers for producing these products. iv) An assessment of the impacts of policy, regulation and government structure on implementing large-scale use of remote sensing technology in this community of users. v) The elaboration of alternative institutional arrangements for operational Earth Observation Data Management Systems (EODMS).

We conclude that an operational EODMS will be of most use to state, regional, and local agencies if it provides a full range of information services -- from raw data acquisition to interpretation and dissemination of final information products. Our major focus is to analyze alternative systems for providing these services.

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PREFACE
(Executive Summary)

This is the final report of an investigation of Earth Observation Data Management Systems (EODMS) to meet information needs of state, regional, and local agency users in a five state midwestern region: Illinois, Iowa, Minnesota, Missouri, and Wisconsin.

The major contributions of this work are:

i) A comprehensive data needs analysis of state and local users.

ii) The design of priority information products that serve state and local data needs and are derivable using remote sensing.

iii) Analyses of the costs, performance, and data management aspects of alternative processing centers to produce the priority products.

iv) The examination of pertinent policy issues in the development of Earth Observation Data Management systems.

v) The elaboration of alternative institutional arrangements for operational Earth Observation Data Management Systems.

We arrive at conclusions and recommendations which differ substantially from common thinking about serving state-level users of remotely sensed data. We conclude that an operational EODMS will be of most use to state, regional, and local agencies if it provides a full range of information services from data acquistion and preprocessing to interpretation and dissemination of final information products. There is a wide gap between the digital format in which raw, satellite-derived information is presently produced by the federal government, and the tabular and map formats in which natural resources information is currently of most use to states. An EODMS which stops short of

completely filling this gap will be of lesser utility than a comprehensive system. Motivated by this fact, we analyze twenty-seven broadly useful "priority" information products which an EODMS might produce from remotely sensed data.

We also recommend that EODMS provide not only satellite-derived information but also a wide variety of natural resources information obtained from satellite, aircraft, and ground survey missions as well as a limited amount of socioeconomic information necessary to produce land use and related products. Most of the information needs we identified appear to require multiple data sources. In evaluating the capability of satellite data to serve state needs, we found that the proposed LANDSAT Follow-on mission promises significant improvement of this capability as compared to LANDSATs 1, 2, and C.

We believe that planning and management of an EODMS system should be a joint state and federal responsibility, structured institutionally in one of two ways. The system might be most responsive to the full range of user needs and might operate most efficiently if a new federal natural resources information agency were established to manage it. However, if creating a new agency appears infeasible, a system which evolves from cooperative efforts among existing institutions such as NASA, USDA, and the Department of the Interior, should receive careful consideration.

In considering how an EODMS might be structured, we find most attractive a regionally-centered system with multidisciplinary processing centers serving groups of states such as our five-state study

region. This structure offers a reasonable balance between economies from shared resources on the one hand, and accountability to users, familiarity with the local area, and product accuracy on the other.

These conclusions on system management and structure result from our analysis of four hypothetical EODMS operational system alternatives. The four include two similar to those mentioned above as well as a system under private sector control and another publicaly-controlled system. We evaluate the four -- and some variations of each -- according to criteria including system capacity and economics, responsiveness, flexibility, ease of implementation and interfacing, and impacts.

We have analyzed in some detail the costs and performance of systems to produce priority products for the five states. We estimate that a multidisciplinary, satellite-based processing center could produce the twenty-seven priority information products for the five state region at a yearly cost of about thirteen million dollars -- including all system overhead charges. Less than fifteen percent of this cost is associated with satellite data acquisition and computer processing, while much of the remainder is due to aircraft and ground survey data gathering and processing. This fact implies that improving sensor performance to reduce ground truth requirements might have a more profound effect on reducing total system costs than would development of more efficient computer processing techniques.

We also compare the cost-effectiveness of producing the priority products for the five states using computer processing of satellite data of LANDSAT Follow-on specifications with traditional processing of aircraft data. The satellite-based techniques cut costs by about

a factor of four and reduce the time required between 50 and 75% while retaining sufficient geometric accuracy to meet user requirements. However, the price paid for these improvements might be a loss of a few percentage points in classification accuracy.

We investigated economies due to resource sharing resulting from centralized processing in a multistate, multidisciplinary center. Sharing resources among disciplines seems, by one measure of comparison, to save about one quarter of the costs that would be incurred if no sharing takes place. Centralizing processing geographically also results in savings; five state centers appear to cost forty-five percent more than one regional center serving our area. However, centralizing to one national facility apparently saves at most another five or ten percent while risking loss of contact with users.

The methodology and focus of this study set it apart from other data needs analyses and system design studies. This study is one of the few data needs analyses for remote sensing whose primary concern is potential users in state, regional and local government. Of the few needs analyses done for this group, this is the only one whose final goal is to outline and assess system alternatives to serve them. In addition, our method of identifying needs is unique; we worked extremely closely over an extended period with the agencies we studied, observing their activities and identifying the tasks they carry out. It is from the results of this close working relationship -- not from short interviews or analyses of statutory responsibilities alone -- that we gained our understanding of agency information requirements.

Feedback from our agency partners proved that carrying out our assessment in this manner has resulted in a realistic and more complete description of their activities, data needs, and capabilities.

As a system design study, a distinctive feature of this project is our careful adherence to a real-world, rather than theoretical, context throughout. The products our systems are designed to produce can serve real needs, which exist today in day-to-day activities in the agencies. Furthermore, our technical analyses are based on observed costs and performance of working systems. In addition, our proposed system management structures take into account current state and federal institutions, together with their governing laws and regulations. Finally, we have addressed a considerably broader range of potentially controversial policy issues in order to highlight questions which system designs ought to address.

Although the EODMS project has come a long way in determining how to serve state and local needs for remote sensing, more research is needed. New work should include detailed design and analysis of alternative EODMS systems in conjunction with both user and supplier agencies. Building upon our preliminary systems analyses, detailed design of systems could examine optimal location, size, technical capability, pricing policy, and management schemes for regional multidisciplinary centers and could identify cost/performance tradeoffs in more detail. Further work could also examine how system costs and utility vary with changes in product menu. Much more work needs to be done in investigating strategies for system implementation, including exploring the roles of state, federal, and regional government; analyzing time-phasing of equipment acquisition and software development;

and designing necessary enabling legislation. Finally, a detailed study of the costs and benefits of the proposed systems would be of great use in making an implementation decision, and it could also be done based on our work. If EODMS is to be implemented, the need for such studies is great.

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LIST OF ACRONYMS

A/C	Aircraft
AC	Agricultural Conservation Program
ACS	Automated Cartographic System
APFO	Aerial Photography Field Office
APSRS	Aerial Photo Summary Record System
ARS	Agricultural Research Service
ASCS	Agricultural Stabilization and Conservation Service
B&W	Black and White
B&W IR	Black and White Infrared
BD	Board
BLM	Bureau of Land Management
BLS	Bureau of Labor Statistics
C	Color
CAP	Citizens Advisory Panel
CCT	Computer Compatible Tape
CFM	Cooperative Forest Management Program
COMSAT	Communication Satellite
CPU	Central Processing Unit
CRIP	Critical Resource Inventory Program
CRT	Cathode Ray Tube
dbms	data base management system
DMA	Defense Mapping Agency
DOI	Department of the Interior
EODMS	Earth Observation Data Management System
EPA	Environmental Protection Agency
ERISTAR	Earth Resource Information, Storage, Transformation, Analysis and Retrieval

EROS	Earth Resources Observation System
ERS	Earth Resources Survey
ESSA	Environmental Science Services Administration
FAGR	Floating Arm Graphic Recorder
FEDNET	Federal Information Network
FIC	Federal Information Center
FOIA	Freedom of Information Act
GIC	Geographic Information Center
GS	Geological Survey
GSA	General Service Administration
GSFC	Goddard Space Flight Center
H/A	High Altitude
HDDT	High Density Digital Tape
HEW	Department of Health, Education, and Welfare
HUD	Department of Housing and Urban Development
GCP	Ground Control Point
ILLIMAP	Illinois Mapping Program
INFOSAT	Information Satellite
I/O	Input/Output
IR	Infrared
IRIS	Illinois Resource Information System
L/A	Low Altitude
LACIE	Large Area Crop Inventory Experiment
LANDSAT (formerly ERTS)	Earth Resources Technology Satellite
LARS	Laboratory for Application of Remote Sensing

LARSYS	Laboratory for Applications of Remote Sensing System
LUNR	Land Use and Natural Resources Information System
M/A	Medium Altitude
MLMIS	Minnesota Land Management Information System
MO	Missouri
MSS	Multispectral Scanner
NARIS	Natural Resource Information System
NASA	National Aeronautics and Space Administration
NCIC	National Cartographic Information Center
NCSL	National Council of State Legislatures
NDPF	National Data Processing Facility
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NTIS	National Technical Information Service
OMB	Office of Management and Budget
PDC	Printing and Dissemination Center
PI	Photo Interpretation
P.I.	Prinicipal Investigator
PNA	Preliminary Needs Analysis
PSU	Primary Sampling Unit
RADAR	Radio Detection and Ranging
RADC	Rome Air Development Center
RALI	Resource and Land Investigation
RBU	Return Beam Vidicon
R&D	Research and Development
RPC	Regional Planning Commission
RMC	Regional Multidisciplinary Center

RS	Remote Sensing
SAB	Space Application Board
S&D	Scanned and Digitized
SCS	Soil Conservation Service
SRS	Statistical Reporting Service
SUNY	State University of New York
TAC	Technology Application Center
TERSSE	Total Earth Resource System for the Shuttle Era
UDDCER	User Data Dissemination Concepts for Earth Resources
U.S.	United States
USBM	United States Bureau of Mines
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
UTM	Universal Tranverse Mercator

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This report represents the efforts of many Washington University personnel whose names do not appear on the title page. We are especially indebted to Sally Bay and Trude Foutch, former research associates with the project who contributed greatly to earlier portions of our study. Other students and research staff of the Center for Development Technology also assisted in the preparation of this report. They include A. Culler, K. Makin, G. Osner, B. Zuckerman, M. Power and J. Huisinga. Special thanks are also due to the Center for Development Technology staff including E. Pearce, D. Williams and G. Robinson whose extra efforts beyond their regular outstanding work helped complete this report during the holiday season.

CHAPTER 1. INTRODUCTION

1.1 OBJECTIVES

The project on Earth Observation Data Management Systems (EODMS*) at Washington University, St. Louis, was funded by NASA for the period July 1974 to December 1976. The primary project goal was to explore ways in which Earth observations data might be delivered to state, regional, and local government agencies to assist in carrying out the functions of those agencies in fields such as natural resources management, agriculture, and environmental protection. The project was executed in the Center for Development Technology by an interdisciplinary research team whose members have backgrounds in engineering, geology, geography, environmental sciences, computer sciences, and public policy analysis.

The formal project objectives as stated in the contract were to:

i. Determine the role of Earth observation satellites in providing data in a form useful to local, state and regional organizations in a variety of fields of application.

ii. Develop an understanding of present data requirements and the ways these requirements are currently being met for potential users of Earth observation data.

iii. Develop a baseline information set concerning current and future use of these data for a five state (minimum) area including Missouri, Illinois, Iowa, Minnesota and Wisconsin.

iv. Establish working relationships with key state agencies.

v. Outline possible alternatives for future operational EODMS delivery systems based on numbers i through iv above, and indicate the most promising alternatives for future EODMS synthesis and assessment.

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*The phrase "Earth Observation Data Management Systems" means large-scale automated information systems for delivery of products derived from remotely-sensed satellite and aircraft data and other data on an operational basis and in a form useful to agencies and individuals in many fields of application at several jurisdictional levels.

1.2 PROJECT OUTCOMES

1.2.1 Contractual Outcomes

Project objectives were to be accomplished through the delivery of three major products to NASA:

i. A Preliminary Needs Analysis Report,

ii. A User Conference,

iii. A Final Report

The Preliminary Needs Analysis Report was issued in three volumes and 827 pages in December 1975. A Summary Report of 35 pages was issued in February 1976. These reports included an extensive survey of data practices and needs in the study region, along with background analyses of a wide range of technical, political, and legal issues which impact on the use of Earth observation data.

A Conference on Future Directions for Earth Observation Data Management systems, cosponsored by NASA and Washington University, was held in St. Louis in April 1976.* Attended by over 80 representatives of state and local government, various federal agencies, universities, and other interested parties; the conference featured feedback on the Preliminary Needs Analysis Report by users and potential users, as well as a wide-ranging discussion of the future of the use of remotely-sensed information in the five state region.

The present Final Report represents the culmination and major output of the EODMS Project. This report is more focused than the Preliminary Needs Analysis Report. It emphasizes two concepts: 1) development of "priority products" and 2) design, analysis, and evaluation of

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*A Proceedings including the papers and discussion at the conference has been issued.

alternative operational Earth Observation Data Management Systems. The priority products are a set of 27 information products, based heavily on remotely-sensed data from space and aircraft, which could be immediately and broadly useful to state and local agencies. Earth Observation Data Management Systems are institutions designed to produce and deliver these products economically to users with formats, scales, update frequencies and related characteristics that are appropriate to the capabilities of the user community.

1.2.2 Other Project Outcomes

During the course of the EODMS project, a large number of additional technical memoranda, reports, and papers, as well as ten quarterly progress reports were produced. These documents are listed in Table 1-1.

Two project documents are especially noteworthy. The Natural Resources Data Requirements Inventory: Missouri was prepared with the cooperation of the Missouri Interdepartmental Council on Natural Resources Information and its member state agencies. The report contains an extensive catalogue of agency data needs and characteristics organized by application area and task. In addition, it contains information on the current source of each of these data items.

A second noteworthy project document is Potential Contributions of LANDSAT Follow-on to State, Regional and Local Data Needs. Based on our knowledge of state and local data needs and their characteristics, we analyzed the capability of each of six remote sensing systems, including the proposed LANDSAT Follow-on, to meet those needs adequately. That analysis became the framework for synthesis of the priority products reported in Chapter 3 of this Final Report.

Table 1-1: EODMS Project Publications

1. Eastwood, L. F., Jr., "The Development of an Operational Earth Observation Data Management System," <u>1974 Earth Environment and Resources Conference Digest of Technical Papers</u>, pp. 74-75, September, 1974.

2. Hays, T. R. and L. F. Eastwood, Jr., "Remote Sensing Data Use by State Agencies and Related Organizations," Memorandum No. 74/3, (65 pp.), December, 1974.

3. Osner, G. T., "Potential for Remote Sensing Data Use in State and Local Environmental Protection Agencies: An Exploratory Analysis," M.A. Thesis, Program in Technology and Human Affairs, Washington University, Report No. R(T)-75/1, (158 pp.), August, 1975.

4. Eastwood, L. F., Jr., J. K. Gohagan, C. T. Hill, R. P. Morgan, et al., "Natural Resources Data Requirements Inventory: Missouri," (331 pp.), September, 1975.

5. Hill, C. T. and S. M. Bay, "An Overview of the Structure and Functions of Land Use Planning Agencies," Report No. CDTDM-R(T)-75/2, (64 pp.), October, 1975.

6. Gohagan, J. K. and T. K. Foutch, "Applications of Remote Sensing in Agriculture and Forestry," Subcommittee on Domestic and International Scientific Planning and Analysis of the House Committee on Science and Technology, October 25, 1975.

7. Eastwood, L. F., Jr., J. K. Gohagan, C. T. Hill, R. P. Morgan, et al., "Preliminary Needs Analysis Report," (3 Volumes), (827 pp.), December, 1975.

8. Power, M. A., "Computerized Geographic Information Systems: An Assessment of Important Factors in Their Design, Operation, and Success," M.S. Thesis, Program in Technology and Human Affairs, Washington University, Report No. CDTDM-R(T)-75/3, (176 pp.), December, 1975.

9. Eastwood, L. F., Jr., J. K. Gohagan, C. T. Hill, R. P. Morgan, et al., "Summary Report; Preliminary Needs Analysis," (41 pp.), February, 1976.

10. Bay, S. M., "Potential Remotely Sensed Data Products for State, Regional and County Planning," Report No. CDTDM-R-76/1, (31 pp.), February, 1976. Presented at the West Lakes Conference of the Midwest Association of Geographers, October, 1976.

11. Culler, A. L. and C. T. Hill, eds., "Proceedings, Conference on Future Directions for Earth Observation Data Management Systems," St. Louis, Missouri, April 11-13, 1976.

12. Hill, C. T., R. P. Morgan, L. F. Eastwood, Jr., J. K. Gohagan, et al., "Potential Contributions of LANDSAT Follow-On to State, Regional and Local Data Needs," Report No. CDTDM-R-76/2, (29 pp.), July, 1976.

Table 1-1: EODMS Project Publications (continued)

13. Eastwood, L. F., Jr., T. R. Hays, G. G. Crnkovich, "Comparison of Photointerpretive and Digital Production Methods for Four Key Remote Sensing Based Information Products," to be presented at the First Conference on the Economics of Remote Sensing Information Systems, San Jose, CA, January 19-21, 1977.

14. Foutch, T. K., J. K. Gohagan, M. A. Power and M. Ruben, "An EODM System Concept for USDA," Forthcoming.

15. Crnkovich, G. G., "Remote Sensing Data Management System Crop Inventory and Vegetation Cover Mapping," Forthcoming.

16. Huisinga, J., "On Private Sector Demand for LANDSAT-Based Information," Forthcoming.

Other, less formal, project outcomes include development of professional relationships between EODMS staff and users and potential users of Earth observations data in our region. We have participated as observers in the Missouri Interdepartmental Council on Natural Resources Information and with the Southwestern Illinois Metropolitan and Regional Planning Commission. A former staff member has gone on to direct the National Conference of State Legislatures Task Force on Uses of Satellite Remote Sensing for State Policy Formulation. Finally, the expertise of the Center for Development Technology has been strengthened and we plan to continue to contribute to analysis and assessment of space applications projects.

1.3 PROJECT METHODOLOGY AND APPROACH

The EODMS project has been organized around three major tasks:

Task 1

Analysis of the activities, tasks, data needs, and data characteristics of state, local, and regional agencies in the five state region.

Task 2

Engineering design and cost analyses of regional processing centers for production of products to meet significant data needs from Earth observation data.

Task 3

Outlining and preliminary evaluation of alternative institutional arrangements for operational EODMS systems, including consideration of a variety of policy and contextual issues.

Task 1 was accomplished through extensive and intensive interactions with about fifty state and local agencies in the five state region from July 1974 to November 1975. Several hundred data needs were identified and their characteristics determined. We then assessed the technical feasibility and economic and political plausibility of meeting those needs totally or in part from remotely-sensed, Earth observation data. The outcome of this analysis was a list of 78 plausible data needs, 56 of which could be met by 27 EODMS priority products. In general, these products meet a variety of data needs in several areas of application on a regular basis; thereby taking considerable advantage of commonality and economies-of-scale of data processing. The concept of priority products represents an important departure from the current operating concept of meeting user needs on demand principally through provision of LANDSAT photos and digital tapes.

Task 2 was the major focus of EODMS effort during calendar 1976. Using production of the 27 priority products as a system goal, detailed comparison was made of techniques to produce those products from digital interpretation of LANDSAT and other data to techniques based on manual photointerpretation of low-and-medium-attitude photography and ground survey data. Data rates, data extraction algorithms, computer systems, and dissemination methods were examined with an emphasis on common elements which could be shared by different products to reduce costs. Estimates were made of the costs to produce the priority products in a regional center for the five states. These estimates enabled us to examine cost/performance trade-offs, economies of scale, and cost-effectiveness of alternative production methods. While they are subject to all the uncertainty associated with untested technologies, we believe these estimates are the first attempt to deal realistically with all the costs of the use of Earth observation data on an operational basis.

Task 3 continued throughout the project period, with a shift in emphasis from analysis of background issues in the earlier period to outlining of systems and exploration of policy questions more recently. All of our work in this area has proceeded in the context of an EODMS which delivers a range of finished data products to a variety of users at the state and local level. Thus we have examined a series of questions related to EODMS planning, coordination, management, operation and control which arise because EODMS is presumed to interface with the external world in many ways. We have been concerned with participation, access, responsiveness, agency auspices, and the like; as well as with technical problems arising from interaction with other information-acquisition and dissemination activities. To our

knowledge, no other study has attempted to address this range of issues on the synthesis of EODMS systems from the state and local point of view. Four illustrative systems are examined in some detail, and two systems have been identified which, in our view, are especially attractive candidates for further detailed systems studies.

The major new and unique contributions of the EODMS project are the following:

1. A comprehensive data needs analysis of state and local users.

2. The design of priority information products that serve state and local data needs and are derivable using remote sensing.

3. Analysis of the costs, performance and data management aspects of alternative processing centers to produce the priority products.

4. The examination of pertinent policy issues in the development of EODMS.

5. The elaboration of alternative institutional arrangements for operational EODMS Systems.

The major unfinished business of the EODMS project, business for which we were not funded, is in-depth synthesis, design and analysis of alternative systems in conjunction with both supplier and users agencies. If EODMS is to be implemented, the need for such studies is great.

1.4 PLAN OF THIS REPORT

Chapter 2 presents the conclusions and recommendations of the study. Taken together, the Preface, Chapter 1, and Chapter 2 are a convenient summary of the entire project.

Chapter 3 details the development of the priority products concept from the data base of user data needs in Appendix A. Remote sensing systems appropriate to acquisition of raw data for the priority products are identified, and the technical characteristics of those products are specified. Previous data needs studies are briefly summarized and compared to our work in Appendix D.

Chapter 4 presents the engineering and economic analyses of the production of the 27 priority products in regional multidisciplinary processing centers from advanced, or Earth observation, data as well as from traditional data sources. Appendix B is a review of the costs and performance of 14 operational or experimental systems which have produced 7 of the priority products. Appendix C supports Chapter 4 with technical detail.

Chapter 5 discusses in a general way the policy issues which must be addressed in EODMS planning. Included are questions of planning and implementation, scope of EODMS activities, management and participation, product pricing policy, the role of the private sector, and possible outcomes of EODMS implementation. Appendix F briefly summarizes some of the contextual developments which may influence EODMS design, including current state activities in remote sensing and computerized geographic information systems.

Chapter 6 is a development and preliminary evaluation of four EODMS system alternatives, chosen to illustrate different ways to organize delivery of the priority products to users. Appendix E summarizes previous system studies and points out how the EODMS study differs from them. Appendix G presents a summary of the way current systems operate to deliver Earth observation data.

CHAPTER 2: CONCLUSIONS AND RECOMMENDATIONS

2.1 INTRODUCTION; PRIMARY CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations of primary importance are highlighted in this section. The remaining sections of the chapter contain more detailed conclusions and recommendations, organized by topic. We present conclusions on data needs, data management practices, and relevant capabilities; the utility of present and planned earth observation satellites in satisfying state data needs; and systems to produce the priority products. We also present recommendations on preferred EODMS system structures and implementation strategies, public and private sector roles in an EODMS, and directions for future research.

It is important to remember that the EODMS study concentrated on state, local and regional government data needs in a five-state region. Our conclusions might have been very different had we emphasized the needs of the federal government, private sector, or other regions.

2.1.1 Primary Conclusions

The format in which existing federal systems produce satellite data is not the format in which satellite-derived information is presently usable by states.

> Although all of the states have experimented with LANDSAT data, no organization in the region has the critical mass of financial resources and computer skills needed to employ satellite data operationally in digital form, in which it contains the most information. Information presented on map products or tables, rather than raw data on imagery or tape, is of most direct use for agency decisionmaking.

An operational EODMS will be of most use to state, regional, and local agencies if it provides a full range of services from data acquisition to processing and dissemination of final information products.

An EODMS which stops short of completely filling the format gap identified in the first conclusion will be of lesser utility than a comprehensive system.

Twenty-seven information products (our "priority products") can help meet most of the significant remote sensing-related data needs of our region's state and local agencies.

We have identified seventy-eight data items which are both widely useful to agencies of the five states and technically feasible to derive from current or near-future remote sensing (aircraft or satellite) technology. Fifty-six of these items are contained on twenty-seven "priority" information products that can be regularly produced at apparently reasonable cost.

LANDSAT Follow-On will likely more than double the utility of satellite data to state agencies in our region (by one measure of comparison with LANDSATs 1, 2, and C).

Approximately two-thirds of the twenty-seven priority products can probably be constructed from data with the spatial and spectral resolution and geometric accuracy capability of the proposed LANDSAT Follow-On. On the other hand, probably fewer than one-third of these products can employ data with the limited spatial resolution of the current LANDSAT MSS or the limited spectral resolution of the LANDSAT-C RBV.

An EODMS based on multidisciplinary, multistate processing centers appears to be a promising way to produce the priority products regularly and at low cost compared with other alternatives.

Sharing data and resources among disciplines may cut about one-quarter from production costs/km^2. Centralizing from state to regional processing centers may reduce total charges by about one-third. However, further centralizing from regional to national centers may save only an additional five or ten percent while risking some loss of product accuracy or utility.

The major costs of a satellite-based EODMS delivering the priority products are in processing supporting aircraft data and gathering

ground truth information. Thus improvement in sensors to reduce "ground truth" requirements might have a much greater effect on total costs than an improvement in computer processing techniques.

Our estimates suggest that of the total cost of the satellite-based system, only 10% is directly related to the cost of computer processing of satellite data, while most of the remaining 90% is due to gathering and processing the required supporting aircraft and ground information.

Satellite - based production of the priority products is cost-effective, as compared with aircraft-based techniques.

We estimate that producing the same menu of products costs one-quarter as much in the satellite-based system, improves production times by a factor of two to four, retains required geometric accuracy (when LANDSAT Follow-On data are used), but might lose a few percentage points in classification accuracy.

Forty-one categories of ground cover, all probably machine-derivable from satellite data, appear to provide sufficient satellite-based information to produce eighteen of the priority products.

Each of the eighteen products displays aggregations, subsets, or refinements of the forty-one categories. Refinements are done with additional information gathered from aircraft or ground truth rather than from satellites.

Today's commercial computers can handle all image processing and data management tasks involved in regularly producing the priority products for the five states.

We estimate the image processing load to be less than half the available time on a CDC 7600, for example, leaving the other half for data management and administrative tasks.

2.1.2. Primary Recommendations

Two predominantly public sector EODMS system alternatives appear promising and should be the subject of detailed system synthesis and assessment studies.

They are:

1) an evolutionary system based upon present institutions, and
2) a natural resources information system with regional, multi-disciplinary processing centers.

For both these alternatives, we recommend that regional (or large state) processing centers be included and that the system incorporate a wide range of natural resources data.

The recommendation of regional structure is based both on the economic advantages cited above and on likely accessability to users. The recommendation that the system should handle a wide range of natural resources data is based on considerations of product utility and proper system scope. On the one hand, if the system is limited to a narrowly-defined set of satellite-derivable data, its utility in natural resources management is artifically limited. On the other hand, handling both natural resources data and a broad range of socioeconomic information may exceed proper bounds on system scope.

Planning and management of a regionally - based EODMS should be carried out jointly by states and the Federal government.

State and local needs will best be met if a variety of state and Federal agencies are represented.

The private sector should play an important but carefully delineated role in a publically controlled EODMS

We believe that private sector organizations should act primarily as contractors to perform certain carefully defined services. It does not seem appropriate, however, to vest in the private sector control of an EODMS which is primarily focused on serving state, local and regional government.

EODMS should initially serve regular information needs, but it should grow to satisfy specialized needs for information "on demand."

Regular availability of information products from the system will build user confidence. However, EODMS should plan to construct a specialized "question answering" system. Such a system will be more complex to implement, but it will enhance the value of EODMS to users.

2.2 CURRENT DATA NEEDS, DATA MANAGEMENT PRACTICES, AND RELEVANT CAPABILITIES OF THE STATES

2.2.1 State's Data Management Practices and Data Needs

State agency users of natural resources data are a diverse group, difficult to characterize in a few words. Nevertheless, in this section, we attempt to identify characteristics that many of these agencies as a market for remotely sensed data have in common. Exceptions can be found to the generalizations we make here, but we provide examples to support them.

The basis for these conclusions lies in our interactions with agencies. Conclusions on agency attitudes about data are amalgams of opinions we heard stated and restated throughout our long period of agency visits. Conclusions on data management practices, preferred product characteristics, etc. are founded in the results of our survey of agency needs contained in Appendix A.

<u>Similarities in data needs abound among the five states, in spite of significant differences and incompatibilities in administrative structures and data handling procedures.</u>

> Approximately 80% of the hundreds of data items we identify in Appendix A are required in two or more of the five states. However, different formats for presentation or different names for the same information item often make these overlaps difficult to identify. In some cases, legal requirements on the characteristics of a data item make data sharing difficult. This is the case, for example, for land use maps for HUD, EPA, and the Corps of Engineers.

<u>Current interest centers on map products as opposed to digital, tabular, or other information display formats.</u>

> State agency personnel, legislators, and the general public can readily use and interpret map data, while information in digital form is unfamiliar to most state agency users.

<u>New legislation is rapidly changing the data needs of some agencies.</u>

> New Federal and State laws are requiring collection and analysis of increasing amounts of information, often with inadequate funding and time to do so. Such requirements include

the National Environmental Policy Act, Section 208 of the Federal Water Pollution Control Act Amendments of 1972, the Flood Disaster Protection Act of 1973, and the Minnesota Environmental Policy Act of 1973 (analogous to NEPA).

State Agencies are often required to handle "brushfire" data gathering projects. For this and other reasons, a significant fraction of the data agencies use is gathered "on demand."

A significant (but difficult to estimate) fraction of data gathering projects are typically inspired by forces outside agency control. For example, engineering site evaluations performed by state geological surveys are usually initiated because construction is planned.

Some agency data gathering projects are extremely localized. A large-scale, remote-sensing based information system is not likely to play a significant role in these activities.

For example, engineering site evaluations require extensive on-site investigations.

Much data as well as advice and assistance in data collection comes to state gencies from the Federal government.

For example, the state agriculture departments of the five states rely almost exclusively upon data generated by the variour branches of USDA. In addition a high level of cooperation exists between the state geological surveys and the USGS in cooperative topographic mapping and water resources data gathering and analysis programs.

Redundancies, inadequacies and gaps exist in Federal and state data gathering efforts.

Space limits us to citing only a few examples of these problems. Specific redundancies exist in the forestry area where soil maps and moisture status data are gathered by the United States Forest Service, state forest services and the Soil Conservation Service. Inadequacies in data timeliness, accuracy and level of detail exist in nearly every agency surveyed. For example, data on wildlife census, population, habitats, and ecology is gathered too infrequently to be of much use in wildlife management. One of many major gaps- a crucial area in which information is often absent - is in water resources. The amounts, location and quality of water resources are unknown for many areas of the country. Many resource management plans require inputs from ground and surface water models, but much of the necessary data is unavailable.

The willingness of state agencies to use information products depends on their confidence in the accuracy of the product, on the amount of input they have in the design of the product, and on a guarantee of continuity of data flow.

> The USDA and USGS supply information products which rate highly on these criteria and which serve many agency users.

2.2.2 State Capabilities, Activities and Attitudes on Remote Sensing

During our agency contacts in the five-state region we found that all the states are experienced users of aircraft data and that they have been experimenting with LANDSAT data. Interest in the latter is high, as is the potential for growth. However, state agencies will invest in new applications of remotely sensed data only if they are convinced that the investment will be beneficial and if they are assured of data quality and continuity.

Many agencies in the five-state region are experienced users of aerial photography and other types of aircraft remotely sensed data.

> The Missouri Geological Survey employed low altitude aircraft data in conjunction with LANDSAT-1 and NASA high altitude photography to locate man-made water impoundments under the National Dam Safety Act. The Iowa State Remote Sensing Laboratory (Iowa Geological Survey) used aerial photography to measure the extent of flooding on the Mississippi and Nishnabotna Rivers, to detect changes in land use and to locate areas of environmental concern. Illinois uses aerial photography in monitoring surface mined lands as well as water pollution problems in the Fox-Chain-of-Lakes region. Wisconsin and Minnesota utilize aircraft data in (lake) coastal zone management and in monitoring critical environmental areas.

Experimentation with satellite remotely sensed data is occurring in all states in the region.

> The Missouri, Illinois and Wisconsin State Geological Surveys have used LANDSAT in geologic mapping. The Iowa Remote Sensing Laboratory in the Geological Survey has utilized LANDSAT digital data and imagery in geologic mapping, water resource studies and environmental monitoring. The Minnesota State Planning Agency is using satellite remotely sensed

data in the establishment of a system to provide land use management information. The Minnesota Geological Survey is also using LANDSAT data in the determination of land suitability in the Twin Cities area. The Southwestern Illinois Metropolitan and Regional Planning Commission is contracting with private industry to produce land-use maps for the Southern Illinois region from LANDSAT CCT's.

Each of the five states would need to make substantial new investments to be able to use raw satellite data effectively in a significant fraction of their day-to-day operations.

The state resources for personnel, training, equipment and funds now devoted to remote sensing are inadequate for operational use.

Individual state agencies are generally reluctant to make new investments in satellite data processing facilities unless substantial benefits at relatively small marginal costs can be demonstrated.

If remotely sensed data and its associated processing technologies are available only at large marginal costs, individual state agencies will be unwilling to invest because of an inability to justify major budgetary revisions or significant agency reorganizations - e.g. a new data processing department - regardless of how good the data are. It is difficult to spend large sums for data acquisition in these agencies because they may be unable to reduce personnel costs due to civil service or other constraints. In addition, in many institutional environments this would be most unlikely, because the more people an agency has, the greater is its power. These facts imply that remotely sensed data should be made available to user agencies, at least initially, at relatively low marginal costs.

2.2.3 Computer Capabilities of the Five States. Developing Computerized Geographic Information Systems in our Region and Elsewhere

We assessed agency computer capability during our visits. In addition, we reviewed the history, technical design, and success or failure of some thirty computerized geographic information systems in the five states and elsewhere.

In general, State agency computer capabilities are not great and are directed toward administrative, rather than research or natural resources data management tasks.

One exception, however, is the Illinois Water Survey, which makes extensive use of computers in data file management, graph preparation, and hydrologic data manipulation and modeling tasks.

Missouri plans to centralize and enhance its computer capability.

Plans call for users to be grouped by functions and for computer power to be centralized into three or four large "host" data centers in Missouri. Compared to the many small computers now dispersed throughout many agencies, the few large host computers will realize gains in efficiency and in computer time available to the individual agency.

Natural resource information systems are being developed by three of the five states.

The Minnesota State Planning Agency has designed a system (MLMIS) which combines a variety of natural resource and socioeconomic data to aid in land use management. The Northeast Illinois Regional Planning Commission has developed a resource information system (NARIS) for land use and regional planning purposes in eight counties. Plans are to extend it to IRIS, a statewide system. ILLIMAP is a tool for mapping natural resources information developed by the Illinois Geological Survey. The Missouri Interdepartmental Council on Natural Resources Information is planning to develop a system to serve all Missouri agencies active in natural resource management. An EODMS should build upon or interface with these systems if feasible.

Our nationwide study of over thirty computerized geographic information bases has identified common factors in system success.

Measured by user acceptance, systems built within the using agency are best; those built by a university are of varying quality. When agencies have depended on private contractors to develop systems, results have generally been less satisfactory.

Challenges in system design include hardware factors (incompatibility of similar computers and slowness of digitizing and automatic scanning equipment), software factors (lack of development and/or standardization of georeferencing systems, and organizational factors (availability of firm funding, continuity of leadership, commitment to the determination of user needs and participation of users in system planning).

2.3 THE CAPABILITY OF PRESENT AND PLANNED EARTH RESOURCES SATELLITES TO SATISFY STATES' DATA NEEDS

We analyzed our data base of user needs to determine how many of these needs can be satisfied by present and future Earth Resources Satellites. We identified seventy-eight aggregated data items that are both widely applicable and feasible to produce using remote sensing. The following statements assess the capability of satellites to deliver these items.

LANDSAT digital output contains more information than LANDSAT photographic imagery but is not widely used because of high interpretation costs, uncertain availability, and inadequate spatial resolution.

Few agencies now have the staff or computer capability to handle digital satellite data. They are not inclined to develop this capability because of the problems mentioned.

Multiplatform remote sensing systems are required for most state and regional agency tasks.

State agency tasks are not totally dependent upon any one method of remote sensing. In most cases a multilevel program of satellites, low and high altitude aircraft photography, and ground investigations are required to achieve best results. The input mixes recommended or used in practice for satellite-based information products (see Chapters 3 and 4) exemplify this requirement.

Of the seventy-eight data items, thirty-one can be supplied solely by current or anticipated satellite platforms and sensors. Most of these items are in areas in which a synoptic view is more valuable than detailed resolution, such as in mineral resources and geology. Twenty-one additional items require aircraft remote sensing in one or more applications areas while satellites suffice in others. Twenty-six of the seventy-eight data items require aircraft remote sensing in all applications areas. Major areas in which LANDSAT data is generally inadequate include forestry, wildlife, engineering and environmental geology, environmental protection, and regional and local land use planning.

LANDSAT 1 and 2 data have very limited applicability for local (i.e. municipal or other substate) applications.

Because of the small scale, low resolution, and broad area coverage of LANDSAT 1 and 2 data, it is unsuited for most local agency applications. The great majority of local agency uses for remotely sensed data require low altitude, high resolution aerial photography. Programs of privately supplied aircraft overflights are current sources of the kinds of data required. Very detailed data are required on subjects as diverse as sidewalk and curb condition, population estimates, and Level III and IV land use.

Development of sensors to the proposed LANDSAT Follow-on specifications promises a major improvement in ability of satellites to meet state agency data needs.

: If remotely sensed data is to be of significant use to state/regional/local users, the spatial and spectral resolution of available satellite sensors needs to be improved. Even when used in conjunction with some aircraft ground truth less than 50% of remote-sensing-performable agency needs can be met with 80m resolution sensors, while 75-80% of these needs could be met with the 30m resolution and improved spectral resolution of LANDSAT Follow-On with aircraft support.

In addition, improvement in sensors leads to major improvements in the cost of information product production. The priority information products would cost three times as much to produce using aircraft data alone as with a combination of 30m satellite and aircraft data. Even with high resolution satellite sensors, only 10% of product cost is directly related to computer processing of satellite data, while most of the remaining 90% is due to gathering and processing the required supporting aircraft and ground information. Thus improvement in sensors to reduce ground truth requirements might have a much greater effect on total cost than would improvement in computer processing techniques

LANDSAT Follow-On may offer substantial improvements in the accuracy of information products based on satellite data.

The seven-fold increase in number of pixels per frame should alleviate the "mixed pixel" problem (signature averaging near sensor resolution limits) in some locations. Enhanced radiometric and spectral accuracy should also improve classification performance. Moreover, geometric accuracy should improve to the USGS standard for 1:24000 scale maps.

2.4 PRIORITY INFORMATION PRODUCTS FOR THE FIVE-STATE REGION AND DATA MANAGEMENT SYSTEMS TO PRODUCE THEM

Lack of data hinders agency decisionmaking, but costs limit remote sensing's potential to supply much of the needed data. Costs of both aircraft-based sensing methods and satellite data processing are high. However, both often lend themselves well to multidisciplinary processing, in which resource sharing can significantly reduce costs to each user.

Multidisciplinary processing to share cost is a feasible idea. Our twenty-seven "priority products" contain many data items in general demand in the region, and our analysis shows that costs per product fall significantly from present levels when these products are produced by a centralized, efficient, satellite-based system.

The twenty-seven "priority" information products are of general utility to agencies in the five states.

> The priority products contain information useful in the following application areas: agriculture, environment, fish and wildlife management, forestry, geology and mineral resources management, state, regional, and local land use planning, and land reclamation, parks, recreation, transportation and water resources management.
>
> As another measure of their utility, the priority products contain fifty-six of the seventy-eight data items which are both feasible to produce by remote sensing and in general demand by agencies. Most of the remaining twenty-two items not contained in the products were eliminated because they were judged too costly to produce on a massive scale.

The priority products do not contain all data needs which an EODMS could possibly serve.

Of the twenty-two items not included on the priority

products, many must be gathered "on demand," to serve an unpredictable need. One example is data on damage to crops.

The EODMS should eventually go beyond the production of a set "menu" of priority products to a capability to answer unpredictable questions on demand. A system which regularly produces a fixed menu of products is typically much less complex than an interactive, "question answering" system. The former system is simpler to implement and debug. Thus, an attractive EODMS implementation strategy would be to build the simpler system, use it to gain widespread user support, and then enhance its capabilities.

We believe that raw satellite imagery or satellite data classified into 41 ground cover classes provides all needed satellite input to priority product production. In almost any geographic region, prior classification into seven aggregate classes reduces the number of classes to be extracted in an area to 10.

All but one of the satellite-based priority products can be derived from the following seven aggregates of the 41 "basic" ground cover classes: Urban/Industrial (9 classes), Agricultural (6 classes), Forested (5 tree type classes and 5 density classes), Other Natural Vegetation (5 classes), Water (7 classes), Non Vegetated, Non Urban (3 classes) and Other (1 class). A priori knowledge or ground truth often permits separating an imaged area into regions based on seven aggregate classes. The maximum number of classes which must be extracted from any such region is ten, including one "other" class.

The priority products in final form are based on further refinements of the satellite-derived classes, which must be done manually using aircraft data and ground survey information. The one satellite-based product not derivable from machine-interpreted satellite imagery is the geographic map, which uses manually interpreted raw imagery.

Many of the priority information products can be assembled from LANDSAT data with current or "Follow-On" specification.

Of the twenty-seven priority products,

- 67% can employ satellite data of 30 m resolution or coarser as a useful input.
- 30% can employ satellite data of 80 m resolution or coarser as a useful input.
- 54% of the 24 map products are useful at a scale of 1:125,000 or smaller, implying a geometric accuracy requirement of $\pm$ 72 m (7/8 of a current LANDSAT pixel). This accuracy has been achieved with LANDSAT data.

- All of the 24 map products are useful at a scale of 1:24,000 or smaller, implying a needed geometric accuracy of ± 12.7 m or 4/10 of a 30 m LANDSAT Follow-On pixel, a fractional pixel accuracy right at the current state of the art of geometric correction systems.

- 89% can be used when updated annually or less frequently, allowing sufficient time for all computer classification, ground truthing, photointerpretation, compilation, and computer-aided printing.

Processing the required yearly satellite data load for the priority products for the five states is well within the capability of current, commercially available third-generation computers.

About fifty-four equivalent satellite images per year must be corrected and classified into one or another subset of the 41 basis classes to produce the priority products for the five-state region. With current LANDSAT imagery, this implies a throughput rate which uses about 45% of the capacity of a Univac 1110. Follow-On imagery would increase this throughput to 45% utilization of a CDC 7600.* These figures include overhead estimates for the operating system, etc. Spare capacity could be used for data base management, administration, or research.

The timeliness of the priority products improves significantly when satellite data and computer techniques are used.

We estimate that the information on the priority products for the five states produced by a photointerpretation-based system would be 21 months old, on the average, when it arrives at user agencies. This compares with an estimated average age of 10 months in the satellite-based system, a 52% improvement. This fact is extremely significant for the ten priority products that are produced either on demand or with an annual or shorter update frequency. Of course, it would be feasible to produce a classifed satellite image from the computer processing system in a matter of hours or less in an emergency. However, this product would not benefit from interactive classification or ground verification, which could take weeks.

A limited body of information leads us to expect that accuracies of both location and classification for the satellite - based system will approach those of an aircraft - based system, assuming LANDSAT Follow-On data are used.

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*Computers for illustration only.

LANDSAT Follow-On data appear to have the potential for geometric correction to USGS standards for 1:24,000 scale mapping. With sufficient aircraft and ground support, classification accuracy might average significantly more than 86% for satellite - based products, as compared to 90% for the same products produced by traditional means. The 86% figures is an observed average for LANDSAT 1 and 2 data and for experimental image process techniques, and we expect that improved techniques will enhance this performance. It is well to note that small increases in classification accuracy may lead to large increases in both production cost and the value of the final information product.

The most intensive possible use of satellite data and computer classification in a multidisciplinary regional processing center cuts cost by about 70% over a system which does not use these techniques, for an area modeled on the five-state region.

Even when all satellite data preprocessing costs are charged to the regional processing center, producing a year's menu of the priority products costs about $13 million for an automated system using satellite data. This cost estimate includes all computer costs, operator charges, aircraft and ground truth missions, photointerpretation, compilation, cartography, and amortized capital costs for buildings and equipment. The estimate compares to one of $48 million for a regional center using only aircraft data and manual photointerpretation and map compilation. These estimates may be in error by 20% or more, but we believe that their relative magnitudes are correct, since the same assumptions were used in deriving both figures.

Satellite - based production of the priority products is cost-effective, as compared with aircraft-based techniques.

The preceding three conclusions support this statement.

Multidisciplinary processing for priority product production in the region makes significant cost reductions possible even when no satellite information or computer classification is employed.

Economies of scale, seasonal variations in demand on production resources, and overlapping aircraft and ground truth requirements are factors in this reduction. Eight products which we analyzed in detail show an average cost/km^2 reduction of 24% if a multidisciplinary facility is used as compared with producing them independently.

<u>In the five-state region, centralizing processing from five state centers to one multistate facility results in significant cost savings.</u>

We estimate a total cost savings of 45%. Further centralization in one national facility may reduce total costs by only another five to ten percent, however. This savings may be offset by reduced user access and by some loss in interpretation accuracy due to lack of familiarity with local conditions.

<u>Improvements in satellite sensors to reduce ground truth requirements might have a more profound effect on total cost than improvements in computer processing techniques.</u>

Of the costs of the satellite-based system, about 10% are directly associated with satellite data processing, while much of the remaining 90% consist of aircraft and ground truth data gathering and processing.

Of course, as sensors improve, the data load will increase for a given rate of product production, pushing up processing costs on a given computer system. However, a more sophisticated system could handle the increased load less expensively, and, as the next conclusion shows, there will be room for this type of improvement within the current state of the art of computer technology.

2.5 RECOMMENDATIONS FOR EODMS STRUCTURE AND IMPLEMENTATION

<u>To serve public sector users, two Federally-run EODMS structures appear to be attractive candidates for implementation.</u>

The first is a system based on present institutions in which an interagency council involving NASA, USGS, USDA and other institutions pools their resources to deliver priority information products with a minimum of duplication to state, local and regional users. Although the structure of such a system would seem to favor "disciplinary" (i.e. existing mission-oriented agency) approaches, we believe it is important that ways be found to develop multidisciplinary processing facilities. We also believe that a substantial amount of processing should be carried out at the regional or large-state level.

The second promising alternative involves the creation of a natural resources information system with regional or large-state multidisciplinary processing centers. The centers should have substantial policy and working level involvement with state, regional and local agencies. In several respects, this alternative appears the most attractive to us. However, it may require the creation of a new government agency for implementation. We believe that such a step may prove to yield substantial benefits and should receive serious consideration. Most of the recommendations which follow are based on this structure.

<u>A system under private sector control is unlikely to be an appropriate mechanism for providing services to state, local, and regional agencies.</u>

Many opportunities for private sector contract activities will exist, however. Producing specialized information products (or some of the priority products, if market conditions allow), serving "on demand" data needs with tight time constraints, and contracting for aircraft and ground data acquisition and for development and maintenance of EODMS facilities are a few examples.

<u>Several EODMS functions appear to be best performed on a national level.</u>

These include acquisition and preprocessing of raw satellite data, system management, some R&D planning, and production of information products of national interest. Reasons

include economies of scale and the plans and expertise of existing institutions such as NASA's National Data Processing Facility and DOI's EROS Data Center.

Primary EODMS product production activities should take place in a multidisciplinary, regional (i.e. multistate) center.

Major savings (24%, according to one calculation) are realized in a multidisciplinary center by sharing resources among disciplines. Overlaps and economies of scale available in a multidisciplinary system include:

i) data needs common to many agencies
ii) production steps common to many products
iii) seasonal variation in data needs and input availability
iv) ground truth requirements for many products obtained simultaneously served from one field excursion.

Based upon our calculations for the five-state study region, regional processing centers can well utilize efficient, large scale third generation computers (for processing, overhead, administration, and data base management functions), while state centers probably could not. Because of this and other factors, centralization from state to multistate processing facilities could save about 45% in our region.

There are arguments against taking centralization to the extreme by implementing one national data processing center. Much of remote sensing data processing is still an art, requiring familiarity with the local area to get best results. Moreover, state agencies will have more confidence in information products which they have helped to produce, and products which they have had a hand in designing will be the most useful to them. Finally, centralizing from ten multistate to one national facility might reduce costs by only another five to ten percent. Thus, a centrally located, regional processing center seems to offer both efficiency of production and accountability to users. Furthermore, it may serve to alleviate potentially negative effects of centralized control of information.

The EODMS should be jointly staffed, managed and funded by state/local/regional and federal agencies.

An EODMS can only succeed if it taps the remote sensing expertise available at the federal level. It also needs local

knowledge and perspective to apply this expertise. Therefore, an EODMS must be administered and operated in such a way that both the federal and non-federal users contribute to it. Cost and staff-sharing will also encourage use, continuity, and a feeling of participation which is vital if such a system is to succeed.

Consideration should be given to making the regularly produced priority products available to all users at a low price as a matter of policy.

The public benefits from the priority products to a wide variety of users may be large and difficult to identify or quantify, analogous to the benefits which accrue from the census or the topographic map program. Rather than full cost recovery charges to one or a few users, public policy may best be served under these conditions by charges for reproduction costs to all users with subsidy from general revenues if needed.

EODMS plans should take cognizance of potential political and legal opposition due to public concern over privacy and the power of big government.

Many citizens have become concerned over the increasing role of government in the management of everyday public and private affairs, even though there are good reasons for strong government in an advanced technological society. Parodoxially, individual citizens and organizations, including business firms, are likely to demand equal functional access to EODMS data products while demanding protection from the potential of EODMS to learn more about them. The Privacy Act of 1974 may exert an as-yet untested constraint on disclosure of information regarding specific geographic locations.

EODMS should maintain a user affairs branch.

A user affairs branch at every regional EODMS center would serve as an interface between the user community and the staff. It should include persons who are aware of both user problems and remote sensing technological capability.

In addition, the changing environment of user agencies means that user needs will have to be assessed continuously so that the EODMS can keep up with changing demands for products and services.

In a publically-controlled EODMS, a substantial but carefully delineated role should be defined for the private sector.

Producing of specialized information products (or some of the priority products, if market conditions allow), serving "on demand" data needs with tight time constraints, contracting for aircraft and ground data acquistion and for development and maintenance of EODMS facilities are a few example roles. Careful delineation of the private sector role is necessary in view of the traditional involvement of public sector agencies in certain aspects of information dissemination and to avoid possible conflicts of interest which may arise.

An attractive EODMS implementation strategy would be initially to produce some of the priority products regularly, and eventually to develop a specialized "question answering" system to produce custom products on demand.

The products must be available to meet the regularly occurring needs of user agencies at the times when they are required. Regular availability will build trust and confidence in EODMS capabilities among the users. However, producing only regularly needed priority products artificially limits the potential value of the system.

Detailed systems design and assessment studies should be carried out of 1) a natural resources information system with interpretation at regional centers and 2) a system based on present institutions.

Among issues to be investigated are:

- Optimal location, size, technical capability and management of regional multidisciplinary centers.
- Potential role of time-sharing and computer-communication networks in data storage and dissemination.
- Economics of high-quality map printing technology.
- Detailed engineering system design to identify cost performance tradeoffs.
- Variation of system cost and utility with changes in product menu.
- Strategies for implementation, including the role of cooperative state, federal and regional activity as preparation for operational system involvement, and time phasing of product production, equipment acquisition, and necessary enabling legislation.

- The role of the private sector in a public sector EODMS.
- Detailed consideration of the likely consequences of EODMS implementation, and development of policies to cope with these consequences.

CHAPTER 3. DATA NEEDS AND EODMS PRIORITY PRODUCTS

3.1 INTRODUCTION

In this chapter we examine the data needs of agencies in the context of the capabilities of currently available and anticipated satellite remote sensing systems. We determine which data items might be provided through an Earth Observation Data Management System and subsequently prioritize and group them into a set of priority information products in order to establish a basis for design of an operational EODMS. Finally, we examine the appropriate remote sensing technologies for producing each of the products, and we list the characteristics of the necessary input data as a basis for EODMS design.

The data base of user needs included as Appendix A consists of several hundred data items and their characteristics, including format, scale, resolution, update frequency, and so forth. It was generated via intensive interactions with the state, regional and local agencies in our five-state region. Table 3-1 lists agencies which were visited by EODMS staff members. Many other agencies were contacted by telephone or mail.

Three fundamental concepts in this chapter require definition. First, we use the term "data need" to refer to a single "data item" or piece of information which is currently used by agencies in operational or on-going demonstration or research projects; that is, in performance of a task. While the distinction is difficult to make; a "data item" lies closer to primary or raw data than to management information for decisions, i.e., data items are derived from raw data whereas management information is derived from a combination of data items, decision models, and so on. For example, "land suitability"

Table 3-1: State, Regional and Local Agencies Visited

Illinois

Dept. of Agriculture

Dept. of Conservation
Division of Forestry

Environmental Protection Agency
Division of Water Pollution Control
Division of Air Pollution Control

Dept. of Local Governmental Affairs
Office of Research and Planning

Dept. of Mines and Minerals
Division of Land Reclamation

Dept. of Transportation

Southwestern Illinois Metropolitan Planning Commission

Iowa

Iowa Conservation Commission
Forestry Section

Dept. of Environmental Quality
Division of Air Quality Management
Division of Water Quality Management
Solid Waste Division

Geological Survey
Remote Sensing Laboratory

Minnesota

Dept. of Natural Resources
Division of Land and Forestry

State Planning Agency
Division of Environmental Planning

Geological Survey

Twin Cities Metropolitan Council

Missouri

Office of Administration
Division of State Planning and Budget

Dept. of Agriculture

Missouri (continued)

Dept. of Conservation
Division of Fisheries
Division of Forestry
Division of Wildlife

East-West Gateway Coordinating Council (St. Louis Region)

Highway Department

Mid-America Regional Council (Kansas City Region)

Dept. of Natural Resources
Division of Environmental Quality
Air Conservation Commission
Solid Waste Management Program
Water Quality Program
Soil and Water Conservation Program
Land Reclamation Program
Division of Parks and Recreation
Division of Policy Planning and Development
Geological Survey

St. Louis County Air Pollution Control Division

St. Louis County Planning Department

South-East Missouri Regional Planning Commission

Dept. of Transportation

Dept. of Consumers Affairs, Registration, and Licensing
Division of Commerce and Industrial Development

Wisconsin

Dept. of Natural Resources
Division of Environmental Protection
Bureau of Air Pollution and Solid Waste Management
Bureau of Water Quality
Division of Forestry, Wildlife and Recreation

is not a data item; but it is derived by weighing several data items which describe the land, such as slope, soil type, bedrock geology, and population density.

Second, a "priority product" is an information product, composed of decision and task-relevant data in useful format. We have called them "priority products" because the information they contain is in demand and because it can be provided conveniently by remote sensing. Agencies currently use this information in their operations or need it to satisfy their operating mandates, even if they cannot currently obtain it. For example, topographic maps are priority products because of large aggregate demand for many applications and because they are best produced from low altitude photography. Lake trophic status maps and agricultural statistics are priority products because they convey critical information for specific policy decisions and because satellite and high altitude aircraft data are useful in producing them.

Finally, "applications area" refers to the organization of activities within state, regional, and local government, rather than to the organization of academic disciplines. Thus, for example, the application area, Geology and Mineral Resources, refers to the activities of state geological surveys rather than to the use of geological information in other agencies.

3.2 FROM DATA NEEDS TO PRIORITY PRODUCTS

3.2.1 Plausibility of Meeting Data Needs by Remote Sensing

In this section we summarize our assessment of whether remote sensing is a feasible method for fulfilling each data need; and, if so, whether it is plausible to consider meeting the data need by any of six remote sensing systems.

The list of data needs are filtered through three screens as shown in Figure 3-1. Screen 1 asks whether it is technically feasible to meet each data need by any one or more of six remote sensing/platform systems: high, medium, and low altitude aircraft; and LANDSAT I and II, C, and Follow-On. The characteristics of each of these systems are shown in Table 3-2. Those data needs for which we can answer "yes" pass through to the next screen.

Judgements of technical feasibility were based on our understanding of the capabilities of each of the remote sensing technologies as evidenced by operational, demonstration, or research successes or by predictions of success for emerging systems.

Screen II asks whether it would be plausible to meet each data need by any of the six remote sensing technologies. This highly judgmental screen eliminates those data items which can be produced by remote sensing systems, but which in our judgement would not be so produced in the five states. We categorized data items as feasible but not plausible for one or more of the following reasons:

1. Data item is needed very frequently.
2. Data item is obtained at little additional cost or effort along with other data items which must be obtained by non-remote sensing techniques.
3. Accuracy requirements are such that remote sensing is inadequate though feasible through elaborate chains of inference.

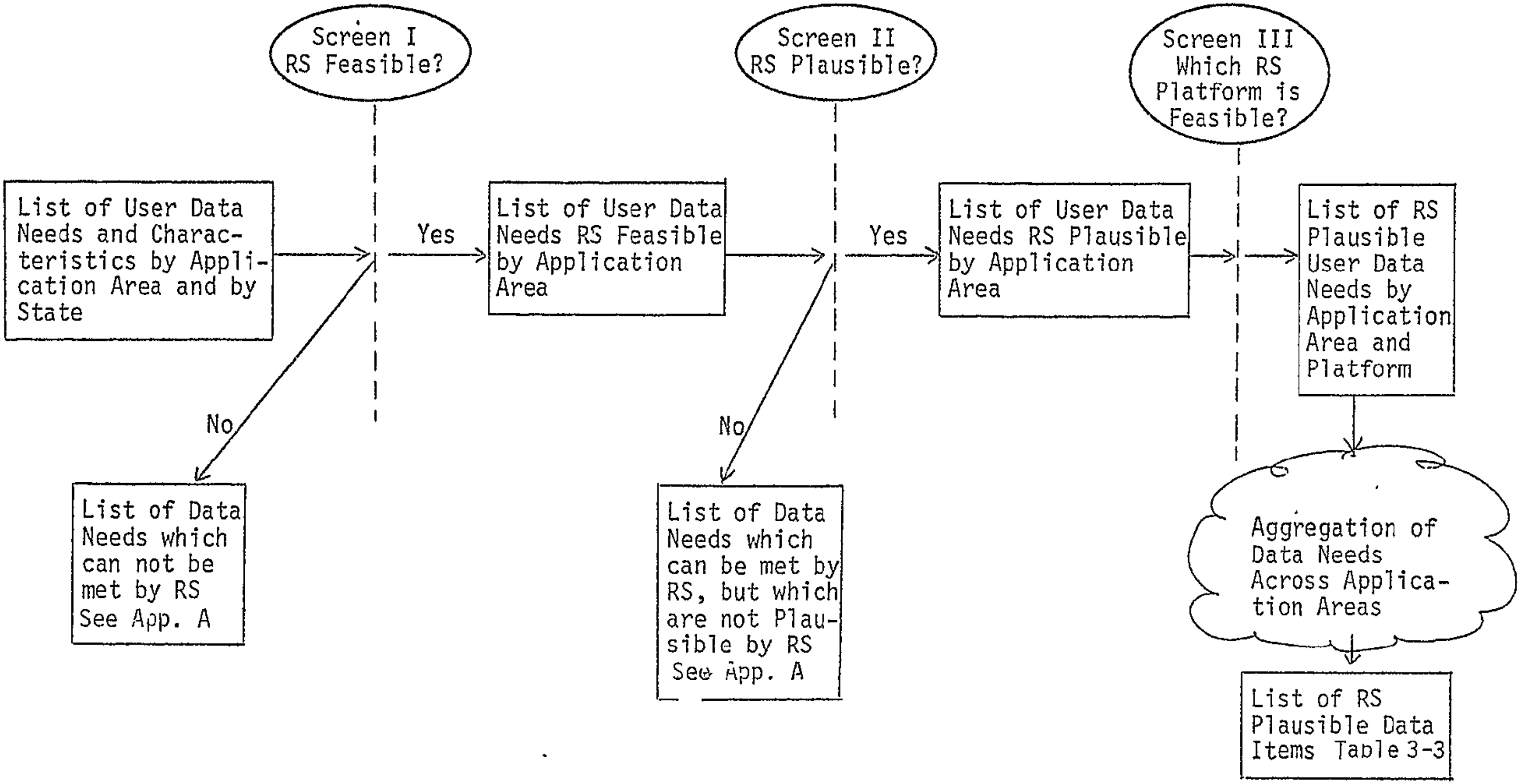

Figure 3-1: Screening Data Needs for Feasibility and Plausibility of Production by Remote Sensing

Table 3-2

Capabilities of the Six Remote Sensing Systems

Technology	Sensor Complement	Resolution	Coverage Period
LANDSAT I,II	4 band MSS	80m	9 days
LANDSAT C	4 band MSS	80m	18 days
	1 band thermal IR	240m	
	RBV	40m	
LANDSAT Follow-On	6 band thematic mapper		9 days
	5 bands	30m	
	1 band	120m	
	5 band MSS		
	4 bands	80m	
	1 band	230m	
Low Altitude Aircraft	Unlimited	0.1-3m	arbitrary
Medium Altitude Aircraft	Unlimited	3-10m	arbitrary
High Altitude Aircraft	Unlimited	5-50m	arbitrary

4. Data item changes very slowly if at all, and sufficient data are already available on the historic record.

5. Legal requirements specify or suggest a non-remote sensing data collection technology.

Throughout this analysis we tried to err on the side of including data items as both feasible and plausible. Those data items which were judged to be either not feasible or not plausible for production by remote sensing are listed in Appendix A.13.

Screen III assigns each data item to one or more remote sensing platforms appropriate to its production. Many data needs can be met by more than one platform, and for some, two or more platforms must be used together, as in multi-stage sampling. Furthermore, very few data items can be produced using remote sensing alone, and for these we assume that appropriate ground truth or other base-line information is available. Finally, we exercised judgement in limiting the use of low and medium altitude aircraft, because nearly all of the data items could be produced this way, but would not be (due to the difficulty of mosaicing or aggregation) if other more synoptic cost-effective technologies were available.

We next aggregated all data items which passed through the three screens. We aggregated across applications areas in order to highlight commonalities as well as differences in the capabilities of various technologies to meet data needs which have the same name but are used for different tasks in different application areas. For example, the multi-spectral scanner on LANDSAT I and II appears to be capable of meeting data need #44 of Table 3-3, which is location and area of mines and quarries, for the purposes of state agencies in the Geology and Mineral Resources and Land Use-State applications areas. However,

the improved resolution of LANDSAT Follow-On may be necessary to meet needs for the same data item to do different tasks in Land Use-Regional/ Local, Land Reclamation, and Parks and Recreation Agencies. Low to medium altitude aircraft system resolution is required to meet needs for the same data item in use in Transportation agencies.

Aggregating across application areas, we concluded with a list of seventy-eight separate, plausible data items, along with notations of feasible remote sensing technologies for each application area in which that data item is needed. This list of the data items is shown in Table 3-3, along with synonyms used in some applications areas. Many user data needs are expressed in terms of time-dependent "change" in these items or in terms of "conversion" from one status to another. Although these concepts are often important, we treat them as implied by the fact that all our data products are updated on a regular basis.

It should be pointed out that the decisions made for Screen III are subject to considerable uncertainty and to considerable disagreement. We made binary, yes-no decisions about whether a data item can be gathered using a particular system. In fact, the question often is not whether a given data item can be obtained but with what reliability it can be obtained. Our "yes" decisions are based on our collective judgement that a good chance exists that a data item can be obtained by the specified system. Furthermore, we often based our judgements on experimental demonstrations, which may not translate to operational capabilities. Finally, LANDSAT C and LANDSAT Follow-On are not yet orbiting, so we had to predict the capabilities of the thermal IR channels, the high resolution RBV, and the thematic mapper. The history of LANDSAT I and II suggests that neither the full capabilities

Table 3-3

Plausible Data Items Which Can Be Produced by Remote Sensing
For One or More Application Areas

Number	Data Item	Synonyms
1	Aeromagnetic and Gravitometric Surveys	
2	Aerosol in Rural Areas: Location, Area Concentration	
3	Agricultural Land Productivity Status: Location, Area	Fallow vs. Cultivated
4	Agricultural Land Use: Location and Area	
5	Aquatic Habitat: Location, Area, Condition	
6	Areal Water Pollution: Source, Quantity, Type	Turbidity
7	Aspect*	
8	Building Condition	Housing Estimate
9	Channelized Stream Length	
10	Construction Materials Access	
11	Dam: Location, Size, Type, Condition	Impoundment
12	Damage** to Crops: Location, Area Degree, Species	
13	Engineering Geology	
14	Erosion of Soil: Location, Area, Rate Type	
15	Field Crop Species: Location, Area, Stage of Maturity	
16	Fish Movement Barriers: Location, Type	
17	Flood Damage	
18	Flooding: Location, Extent, Duration	
19	Flood Plain: Location, Area	
20	Flood Plain Constriction: Location, Area, Type	
21	Flood Prone Area	
22	Forest Conversion Method	

*Aspect is a measure of the orientation of a parcel of sloping land with respect to the sun.

**Can be due to floods, hail, wind, heat, cold, disease, pests, chemicals.

Table 3-3 (Continued)

Number	Data Item	Synonyms
23	Forest Condition: Location, Area	Forest Stress
24	Forest Fire Damage: Location, Area, Degree	
25	Forest Fire: Location, Area	
26	Forest Stand: Location, Area, Composition	
27	Forest Stand Age	
28	Forest Stand Density	
29	Forest Stand Maturity	
30	Forested Land: Location, Area, Conversion	
31	Gaining and Losing Streams*	
32	Geologic Features: Location, Area, Nature, Shape, Height	Geologic Maps, Surface Geology, Generalized Geology
33	Geologic Unit: Location, Area, Structure, Orientation	
34	Grassland Type: Location, Area, Condition	
35	Historic and Archaeological Sites	Prehistoric Sites
36	Industry Location	——
37	Irrigated Land	
38	Lake Shoreline Length	
39	Lake Trophic Level	
40	Land Cover Type	Land Use
41	Land Reclamation Stage	
42	Location of Individual Trees	
43	Mineral Market Access	
44	Mines and Quarries: Location, Area	
45	Natural and Scenic Areas: Type, Location, Area	
46	New Construction	
47	Oil Spills: Location, Area	
48	Pipeline Location	
49	Population Density	Population Estimates

*Certain streams gain or lose significant flow to subsurface streams.

Table 3-3 (Continued)

Number	Data Item	Synonyms
50	Potential Landfill Sites	
51	Potential Park Sites	
52	Public Facilities Location	Energy or Service Facilities
53	Reforested Regions: Location, Area, Condition	
54	Road Location	
55	Rock Type	
56	Rural Water Quality	
57	Slope	
58	Soil Surface Color	
59	Soil Drainage	
60	Soil Moisture Content	
61	Soil Type: Location, Area	
62	Solid Waste Disposal Sites: Location, Area, Condition	
63	Stratigraphic Features: Location, Area	
64	Strip-Mined Land Condition	
65	Surface Drainage	
66	Surface Water: Location, Area, Type Condition	Lakes and Streams, Physical Alteration of Water Bodies
67	Timber Cutting: Location, Area, Amount	Timber Harvest
68	Timber Volume Estimate	
69	Topography	Local Relief, Terrain Type
70	Tree Crop Species: Location, Area	
71	Vegetative Cover Type: Location, Area	Wildlife Habitat
72	Water Impoundment Volume	Water Body Volume
73	Water or Land Radioactivity	
74	Water Pollution Outfall Location	
75	Water Temperature	
76	Water Turbidity	
77	Watersheds	
78	Wetlands: Location, Area	

nor the limits of these sensors will be known until they are flown and tested.

3.2.2 Priority Products

Priority products are information products designed to provide decision-relevant data and information to users. Multiple factors shaped our thinking as we moved from a data base of fundamental data needs and currently used information products to a specification of twenty-seven priority products to be produced by an operational EODMS. We were concerned that the products have multiple uses by many agencies to insure significant demand or be central to the operations of at least one agency. We were concerned that the number of products not be excessive so as not to over-burden the production system. On the other hand, we wanted a variety of multi-purpose and specialty products with a sufficient variety of technical characteristics so as to provide a realistic set of production requirements on which to base EODMS system designs. We were also concerned that the products be based on a significant input of satellite gathered data.

In our Preliminary Needs Analysis (3-1) we tabulated twenty-eight possible candidates for the priority product category. Subsequent analysis of the data base led us to a revised set of priority products. In this analysis we considered priority and extent of demand, cost of production of products under assumptions on system design, feedback from the user community regarding useful products, and appropriate aggregations of data and information into decision-relevant products.

The set of priority products we finally settled on is displayed in Table 3-4. Each product is characterized by a set of features

Table 3-4: Product Characteristics for the EODMS Priority Products

Product	Resolution	Product Scale	Area Covered by One Product	Area Over Which Product Required in Five States	Categories Per Product/ Relevant Categories Derivable from Satellite Data	Product Update Frequency	Additional Formats T = table MO = map/overlay P = photo D = digital	Application Area
forest management map (includes water bodies, forest type, planimetric information, esp. roads, and ownership and political boundaries	30m	1:125,000	4872 km^2	entire area 835,530 km^2	10-15/7	5 years	T; MO, D	forestry, fisheries, land use, agriculture
agricultural management map (includes pasture, rangeland, flood prone areas, drainage basins, and tiled fields)	30m Or 10m	1:24,000	155 km^2	entire area 835,530 km^2	13/10	5 years	T; MO; D	land use, agriculture, fisheries
level I land use map	30m 80m	1:250,000	19,490 km^2	entire area 835,530 km^2	9/9	5 years	T; MO, D	land use, agriculture
level II land use map A	30m 80m	1:250,000 1:500,000	19,490 km^2	entire area 835,530 km^2	28/28	5 years	MO, D	land use
level II land use map B	10m 30m	1:24,000	155 km^2	urban areas (<5% of total)	28/16	5 years	MO, D	land use
vegetative cover type map	30m	1:24,000	155 km^2	vegetative, non-urban areas (85% of total)	20-30/15	annual	T, MO, D	agriculture, forestry, fisheries, wildlife, land use
soil map	30m-80m	1:24,000	155 km^2	selected areas	30/15	20 years	MO, D	forestry, land use
forest stand map	30m with 10% of area sampled with 2m and 10m	1:24,000	155 km^2	forested areas (31% of total)	10-15/5	5 years	MO, P, D	forestry
timber volume estimate table	80m and 10m with 15% of area sampled with 2m	---	one forest (varies)	forested areas (31% of total)	5/5 (density	5 years	T, P, D	forestry, land use
fire measurement map	30m	1:250,000	one forest	selected forested areas (1% of total)	3-5/2	on demand	T, P, MO, D	forestry
water impoundment volume table	30-80m 2m-10m	---	---	water bodies >1 acre (.5% of total)	2/2	annual	T, D	land use, fisheries
lake trophic status map	30-80m	1:250,000	individual lakes (varies)	water bodies >5 acres (.1% of total)	5-10/5	annual	MO; D	land use

Table 3-4: Product Characteristics for the EODMS Priority Products (cont.)

Product	Resolution	Product Scale	Area Covered by One Product	Area Over Which Product Required in Five States	Categories Per Product/ Relevant Categories Derivable from Satellite Data	Product Update Frequency	Additional Formats T = table MO = map/overlay P = photo D = digital	Application Area
recreation map (includes population density, private recreational facilities, potential park sites, natural and scenic areas)	30m	1:125,000	4872 km^2	100 mile radius from major cities (10% of total)	10-30/10	annual	MO, D	land use
industrial map (includes location of industry, quarries, mines, and strip mines)	30m	1:125,000	4872 km^2	selected areas (≈10% of total area)	30/8	annual	MO, D	land use
topographic map	2m-3 3m 5m-10m for update	1 24,000	155 km^2	entire area 835,530 km^2	5-8/0	20 years	MO; P	all
slope map	2m-10m	1:24,000	155 km^2	entire area 835,530 km^2	10-12/0	20 years	MO, P	all
orthophotoquad	5m-10m	1:24,000	155 km^2	entire area 835,530 km^2	N A	5 years	MO	all
structural geology map	2m-30m 80m	1 24,000 1:250,000	155 km^2 19,490 km^2	entire area 835,530 km^2	8/1-2	20 years	MO, P	geology, mineral resource, water resource
geologic map (rock type)	2m-10m	1 24,000 1 62,500	155 km^2 620 km^2	entire area	12/0	20 years	MO	land use, geology, mineral resources, water resource
surficial materials map	2m-30m	1 24,000 1:250,000	155 km^2 19,490 km^2	entire area 835,530 km^2	20/15	20 years	MO; P; D	geology, land reclamation, land use
flood prone areas map	.4m-10m	1:4800 to 1 250,000	data needed for only small portion of 155 km^2 area	flood prone areas - 20% total area	2/0	5 years	MO, P, D	land use, water resources
flood inundation area maps	.4m-10m 30m-80m	1:24,000 or 1:250,000	155 km^2 19,490 km^2	entire area 835,530 km^2	2/2	on demand	MO; D	land use, water resources
earthen dam condition map	<1m-2m	1:24,000	155 km^2	<1%	5/2	on demand	MO, T; D	land use, water resources
drainage basin map	2m-30m	1 24,000 - 1:250,000	155 km^2 19,490 km^2	entire area by state 835,530, km^2	2-6/0	20 years	MO	land use, water resources

Table 3-4: Product Characteristics for the EODMS Priority Products (cont.)

Product	Resolution	Product Scale	Area Covered by One Product	Area Over Which Product Required in Five-State	Categories Per Product/ Relevant Categories Derivable from Satellite Data	Product Update Frequency	Additional Formats T = table MO = map/overlay P = photo D = digital	Application Area
sinkhole location map	2m	1 24,000	155 km^2	selected areas (<1% of total)	2/0	on demand	MO, P	geology, water resources, land use
construction materials availability map	2m-10m. 2m on base 10m on geology data 30m	1,24,000 1:250,000	155 km^2 19,490 km^2	selected areas (<2% of total)	5-6/3-5	20 years	MO, T, P; D	land use, geology
all basin imagery and digital data	---	---	---	---	---	on demand	---	all

which serve to define it. For clarity, we have also included details of the information contents for products, as necessary. For example, the forest management map includes: water bodies; forest type-hickory/oak, soft wood, or other types; roads; ownership and political boundaries. It would be produced on a scale of 1:125,000. Each product would cover approximately 4800 km^2. The total area to be covered in the five-state region would be about 840 thousand square kilometers. It would include 10-15 categories of information, seven of which could be derived from satellite data. It would be updated and reissued every five years. Finally, the information on it would also be available in tabular form, as overlays, or in digital form.

The application areas for the priority products are indicated in Table 3-5. An "A" indicates that the product is especially useful in the indicated application area. An "X" indicates a somewhat lower order of usefulness. A product may find use in other application areas also, but, based on our understanding of the data needs of agencies in the five-state region, the principal application areas are as indicated.

In Table 3-6 we indicate which data item can be retrieved from specific products. Some data items can be extracted directly from one or more specific products or can be extracted straightforwardly using a combination of products, each providing a component of the information. However, if the data item could only be inferred from information embodied in products via some indirect chain of inference we have not indicated a link. Thus, basic imagery, product number twenty-seven, is not identified as a direct source for any data item, although we realize that in the future thermal imagery may provide a direct means of measuring water temperatures.

Table 3-5. Application Areas for Which Priority Products are Useful

Priority Product	Agriculture	Climate and Weather	Environment	Fisheries	Forestry	Geology and Mineral Resources	Landuse - State	Land Use - Local and Regional	Land Reclamation	Park and Recreation	Transportation	Water Resources	Wildlife
Forest Management Map	X			X	A		X	X		X	X	X	X
Agricultural Management Map	A			X			X	X				X	
Level I Land Use Maps	X				X		A				X		X
Level II Land Use Maps A and B							X	A		X	X		X
Vegetative Cover Type Map	X		X	X	X		X	X	X	A		X	X
Soil Map	A				X	X	X	X	X				
Forest Stand Maps					A					X			X
Fire Detection Maps	X				A					X			X
Water Impoundment Volume Tables	X			X						X		A	X
Lake Trophic Status Map			A	X								X	X
Recreational Opportunities Map							X	X		A	X		
Industrial Map			X				X		A				
Topographic Maps	A			A	A	A	A	A	A	A	A	A	A
Slope Maps	A				X	A	X	X	A	X	A	X	X
Orthophotoquads	A		X	X	A	A	A	A	A	A	A	A	A
Geologic Maps						A	X	X	X			X	
Structural Geology Map						A						X	
Surficial Materials Map	X					A	X	X	X		X	X	
Construction Materials Availability						A	X	X			A		
Flood Prone Areas Map	X		X				A	A			X	X	X
Flood Inundation Areas Map			X				A	A				X	
Earthen Dam Condition Map						X							
Drainage Basin Maps	X		A		X		A	A		X		A	X
Sinkhole Location Maps			X			X	X	X			X	A	
Basic Imagery	X	X	X	X	X	X	X	X	X	X	X	X	X

Key: A = Product is of primary importance in specified application area
X = Product is of lower order usefulness, but still of significant value.

Table 3-6 Occurrence of Plausible Data Items on Priority Products

Data Item

Priority Product	Agricultural Land Productivity Status: Location, Area	Agricultural Land Use: Location and Area	Aquatic Habitat Location, Area, Condition	Areal Water Pollution: Source, Quantity, Type	Channelized Stream Length	Construction Materials Access	Dam Location, Size, Type, Condition	Engineering Geology	Erosion of Soil: Location, Area, Rate Type	Field Crop Species: Location, Area, Stage of Maturity	Fish Movement Barriers Location, Type	Flooding: Location, Extent, Duration	Flood Plain: Location, Area	Flood Plain Construction Location, Area, Type	Flood Prone Area
Forest Management Map						X									
Agricultural Management Map	X	X		X						X					
Level I Land Use Map	X	X													
Level II Land Use Map A	X	X		X											
Level II Land Use Map B				X										X	
Vegetative Cover Type Map	X	X	X												
Soil Map				X				X	X	X					
Forest Stand Map															
Timber Volume Estimate Table															
Fire Measurement Map															
Water Impoundment Volume Map							X								
Lake Trophic Status Map			X												
Recreation Map			X												
Industrial Map				X										X	
Topographic Map					X	X									
Slope Map															
Orthophotoquad					X	X	X		X		X			X	
Structural Geology Map															
Geologic Map								X							
Surficial Materials Map						X		X							
Flood Prone Areas Map					X								X	X	
Flood Innundation Area Map												X	X	X	X
Earthen Dam Condition Map							X				X				
Drainage Basin Map				X	X										
Sinkhole Location Map								X							
Construction Materials Availability Map						X									

Table 3-6: Occurrence of Plausible Data Items on Priority Products (continued)

Priority Product	Forest Conversion Method	Forest Fire Damage Location, Area, Degree	Forest Fire Location, Area	Forest Stand Location, Area, Composition	Forested Land Location, Area, Conversion	Geologic Features Location, Area, Nature, Shape, Height	Geologic Unit Location, Area, Structure, Orientation	Grassland Type Location, Area, Condition	Industry Location	Irrigated Land	Lake Shoreline Length	Lake Trophic Level	Land Cover Type	Land Reclamation Stage	Mineral Market Access (Proximity to Transportation)
Forest Management Map	X			X	X								X		
Agricultural Management Map								X		X			X		
Level I Land Use Map													X		
Level II Land Use Map A	X												X		
Level II Land Use Map B									X				X		
Vegetative Cover Type Map				X	X			X					X		
Soil Map															
Forest Stand Map				X	X								X		
Timber Volume Estimate Table															
Fire Measurement Map		X	X												
Water Impoundment Volume Map															
Lake Trophic Status Map												X			
Recreation Map															
Industrial Map									X					X	X
Topographic Map											X				X
Slope Map											X				
Orthophotoquad															X
Structural Geology Map						X	X								
Geologic Map						X	X								
Surficial Materials Map						X									
Flood Prone Areas Map															
Flood Innundation Area Map															
Earthen Dam Condition Map															
Drainage Basin Map															
Sinkhole Location Map															
Construction Materials Availability Map															X

Table 3-6: Occurrence of Plausible Data Items on Priority Products (continued)

Priority Product	Mines and Quarries: Location, Area	Natural and Scenic Areas: Type, Location, Area	New Construction	Pipeline Location	Population Density	Potential Park Sites	Public Facilities Location	Reforested Regions: Location, Area, Condition	Road Location	Rock Type	Slope	Soil Surface Color	Soil Drainage	Soil Type: Location, Area	Stratigraphic Features Location, Area
Forest Management Map								X							
Agricultural Management Map															
Level I Land Use Map															
Level II Land Use Map A	X														
Level II Land Use Map B			X				X								
Vegetative Cover Type Map								X							
Soil Map												X	X	X	
Forest Stand Map								X							
Timber Volume Estimate Table															
Fire Measurement Map															
Water Impoundment Volume Map															
Lake Trophic Status Map		X													
Recreation Map					X	X									
Industrial Map	X			X											
Topographic Map				X			X		X						
Slope Map											X				
Orthophotoquad															
Structural Geology Map															X
Geologic Map										X					X
Surficial Materials Map										X				X	
Flood Prone Areas Map															
Flood Innundation Area Map															
Earthen Dam Condition Map															
Drainage Basin Map															
Sinkhole Location Map															
Construction Materials Availability Map	X														

Table 3-6 Occurrence of Plausible Data Item on Priority Products (continued)

Priority Product	Data Item: Strip-Mined Land Condition	Surface Drainage	Surface Water Location, Area, Type Condition	Timber Cutting Location, Area, Amount	Timber Volume Estimate	Topography	Tree Crop Species: Location, Area	Vegetative Cover Type: Location, Area	Water Impoundment Volume	Watersheds	Wetlands Location, Area
Forest Management Map			X								
Agricultural Management Map											
Level I Land Use Map											
Level II Land Use Map A			X								X
Level II Land Use Map B											
Vegetative Cover Type Map							X	X			X
Soil Map		X									
Forest Stand Map				X			X				
Timber Volume Estimate Table				X	X						
Fire Measurement Map											
Water Impoundment Volume Map									X		
Lake Trophic Status Map											
Recreation Map											
Industrial Map	X										
Topographic Map		X				X					
Slope Map		X				X					
Orthophotoquad		X				X					
Structural Geology Map											
Geologic Map											
Surficial Materials Map		X									
Flood Prone Areas Map											
Flood Innundation Area Map											
Earthen Dam Condition Map											
Drainage Basin Map		X								X	
Sinkhole Location Map											
Construction Materials Availability Map											

Twenty-one of the seventy-eight plausible data items cannot be extracted from our priority products. These are listed in Table 3-7. Among the reasons why we did not design products to correspond to these are:

Random demand - would reduce productivity

High frequency, low response time - cost to produce would be extremely high

High resolution sensors required - would make production cost high

Current collection methods are sufficiently good and economical

Table 3-7: Plausible Data Items Not Directly
Extractable from Priority Products

Item
Aeromagnetic and Gravimetric Surveys
Aerosol in Rural Areas
Aspect
Building Condition
Damage to Crops (Acts of God: pests, disease, etc.)
Flood Damage
Forest Condition - Stress
Gaining and Losing Streams - Loss or Gain of Flow Volume
Historic and Archaeological Sites
Oil Spills
Location of Individual Trees
Population Density
Potential Land Fill Sites - Location and Suitability
Rural Water Quality
Soil Drainage
Soil Moisture Content
Solid Waste Disposal Sites
Water or Land Radioactivity
Water Temperature
Water Pollution Outfalls
Water Turbidity

3.3 SYSTEM DESIGN IMPLICATIONS OF THE PRIORITY PRODUCTS: PLATFORMS AND INPUTS

3.3.1 System Input Data Characteristics

Systems design depends heavily on the characteristics of the input data to be processed, the frequency with which products are to be produced, and the geographical scope for products. Frequently-produced products, requiring high spatial resolution, and covering large geographic areas demand higher-throughput, larger-capacity systems than products with the opposite characteristics. From our data base (Appendix A), land-cover statistics for Missouri, and the analysis presented in Section 3.2, we specified the geographic extent for products and the frequency with which they must be updated. We have also determined the limits on spatial resolution for the data items which are incorporated in the products. In this section we characterize the data inputs required for each product in terms of appropriate remote-sensing platform/sensor systems. We refer only to systems which now exist or are anticipated in the near future. We conclude our analysis by summarizing all this information and our resulting estimates of the required number of images per product. The information represents a baseline of information for the study of regional processing centers to produce the priority products in Chapter 4.

3.3.2 Specification of Platforms and Sensors

The capability of each remote sensing platform and its sensor complement to meet the data needs for product production are determined by asking several questions:

1. What data items can be acquired with LANDSAT I or II?
2. What data items might be acquired with LANDSAT C that cannot be with LANDSAT I and II?

3. What data items might be acquired with LANDSAT Follow-On that can not be with LANDSAT I and II or the LANDSAT C thermal channel?

4. For what data items is aircraft remote sensing the only feasible remote sensing technology among the six considered?

Before we discuss the answers to these questions, it is important to reiterate two points. First, very few of the data items are produced by any one type of remote sensing alone. Nearly always, some independent ground truth or other data are required. Second, any particular data item may meet a need in one application area when obtained by a particular remote sensing platform. However, that same data item obtained by that platform may be inadequate to meet a data need in another application area if better resolution or more frequent or random coverage is needed.

Table 3-8 is a list of data items and related application areas for which a satellite having the capabilities of the LANDSAT Follow-On is needed. This table should be of great interest to those who are evaluating the potential contribution of LANDSAT Follow-On. The meaning of Table 3-8 is that LANDSAT I, II, and C (thermal channel) cannot be used, in our judgement, to provide these data items for the applications area marked with a (0).

Note that the 40m resolution LANDSAT RBV may be able to make some contributions to the data items marked in column three. Those data needs marked (*) can be met with LANDSAT I, II or C; and those marked (+) require aircraft rather than satellite data. For the set of data items in Table 3-8, LANDSAT I and II tend to be useful primarily for statewide land use (usually at scales of 1:250,000 or smaller), and aircraft tend to be required in local or regional land use, where great detail is required, or in transportation, which is

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Table 3-8

Plausible Data Items Which Require Follow-On Capability
In At Least One Application Area

NUMBER	DATA ITEM	LANDSAT C RBV HELPS?	APPLICATION AREA												
			AGRICULTURE	CLIMATE AND WEATHER	ENVIRONMENT	FISHERIES	FORESTRY	GEOLOGY AND MINERAL RESOURCES	LAND USE - STATE	LAND USE - REGIONAL AND LOCAL	LAND RECLAMATION	PARKS AND RECREATION	TRANSPORTATION	WATER RESOURCES	WILDLIFE
3	AG. LAND PRODUCTIVITY STATUS		0												
4	AGRICULTURAL LAND USE		*						*	0			*		
6	AREAL WATER POLLUTION				0										
12	DAMAGE TO CROPS	YES	0	+					*	0					
15	FIELD CROP SPECIES		0						0	*					
17	FLOOD DAMAGE	YES													
18	FLOODING	YES								0				0	
19	FLOOD PLAIN LOCATION								*	0			+	*	
21	FLOOD PRONE AREAS								*	0			+		
22	FOREST CONVERSION AREAS						0								
26	FOREST STAND LOCATION						0		0	*					
28	FOREST STAND DENSITY	YES					0								
30	FORESTED LAND						*		*	0					
32	GEOLOGIC FEATURES	YES						0	*	0			0		
33	GEOLOGIC UNITS	YES						*		0					
34	GRASSLAND TYPE		0												
36	INDUSTRY LOCATION	YES					0		0	0					
37	IRRIGATED LAND		0						*						
39	LAKE TROPHIC LEVEL				*				0						
40	LAND COVER TYPE				*		0	*	0	+	*	*		*	
44	MINES AND QUARRIES	YES						*	*	0	0	0	+		
45	NATURAL AND SCENIC AREAS								0	+			+		
47	OIL SPILLS				0										
48	PIPELINE LOCATION									0					
49	POPULATION DENSITY	YES							0	+					
50	POTENTIAL LANDFILL SITES	YES			0										
51	POTENTIAL PARK SITES									0					
53	REFORESTED REGIONS						0								
55	ROCK TYPE							0		0					
56	RURAL WATER QUALITY				0										
61	SOIL TYPE						+	0	*	*		*	*		
63	STRATIGRAPHIC FEATURES	YES						0							
64	STRIP MINED LAND								+		0				
65	SURFACE DRAINAGE					*		*	*	+	+			0	
66	SURFACE WATER	YES				0			*	*	+		*	*	
67	TIMBER CUTTING	YES					0		*						
71	VEGETATIVE COVER TYPE					*	*		*	0	0	0	+	0	0
72	WATER IMPOUNDMENT VOLUME	YES								0				+	
76	WATER TURBIDITY													0	
	NUMBER OF DATA NEEDS FOR WHICH FOLLOW-ON IS REQUIRED TOTAL = 54		5	0	4	1	7	4	7	15	3	2	1	4	1

KEY = 0 FOLLOW-ON REQUIRED
* LANDSAT I OR II ADEQUATE
+ SATELLITES INADEQUATE

a traditional heavy user of medium and low altitude aircraft photos for highway route location and design. Finally, a blank means that the data item is not needed in that application area according to our data needs survey, or that ground survey data are required to do the task.

Measured by number of data items provided, the LANDSAT Follow-On would appear to be most useful for land use agencies (total of 22 items at all levels); followed by forestry, 7; and agriculture, 5. These results reflect, in part, the large number of data items desired by land use agencies at all levels. However, a simple count of data items is not a good measure of the importance of each contribution, since neither application areas nor data needs have equal priority within the states. We do not attempt to judge the relative importance of each of these contributions of the Follow-On. But it is significant that the Follow-On, whose sensors are being tuned to vegetation analysis, does seem to be responsive to state, local and regional agency needs to measure damage to crops, field crop species, grassland type, forest stand condition, and so on; all of which are quite important on any state's scale of data priorities.

In answer to Question 2, Table 3-9 shows those few data needs which can be met by the LANDSAT C thermal channel but not by LANDSAT I or II. Column three of Table 3-8 indicates our assessment of the capability of the 40m RBV to contribute to the data needs.

Table 3-10 highlights those combinations of data items and applications areas which can be met, according to our analysis, by LANDSAT I and II. Since "C" and Follow-On have all the capabilities of I and II, it follows that the entries in Table 3-10 for LANDSAT I and II

Table 3-9

Plausible Data Items Which Can Be Produced by The LANDSAT C Thermal IR Channel

Number	Data Item	Applications Areas
25	Forest Fire Location and Area	Forestry
37	Irrigated Land	Land Use - State
59	Soil Drainage	Agriculture
60	Soil Moisture Content	Agriculture/ Transportation
75	Water Temperature	Environment/Fisheries

Table 3-10

Plausible Data Items Producible by All Satellites
For One or More Application Areas

NUMBER	DATA ITEM	APPLICATION AREA: AGRICULTURE	CLIMATE AND WEATHER	ENVIRONMENT	FISHERIES	FORESTRY	GEOLOGY AND MINERAL RESOURCES	LAND USE - STATE	LAND USE - REGIONAL AND LOCAL	LAND RECLAMATION	PARKS AND RECREATION	TRANSPORTATION	WATER RESOURCES	WILDLIFE
2	AEROSOL IN RURAL AREAS			*					*					
4	AGRICULTURAL LAND USE	*						*	0			*		
5	AQUATIC HABITAT				*			+	+					
12	DAMAGE TO CROPS		+					*	0					
15	FIELD CROP SPECIES	0						0	*					
18	FLOODING								0				*	
19	FLOOD PLAIN LOCATION							*	0			+	*	
20	FLOOD PLAIN CONSTRICTION				*								+	
21	FLOOD PRONE AREAS							*	0			+		
23	FOREST CONDITION					*								
24	FOREST FIRE DAMAGE					*								
26	FOREST STAND LOCATION					0		0	*					
30	FORESTED LAND					*		*	0					
32	GEOLOGIC FEATURES						0	*	0			0		
33	GEOLOGIC UNIT						*		0					
39	LAKE TROPHIC LEVEL			*				0						
40	LAND COVER TYPE			*		0	*	0	+	*	*		*	
44	MINES AND QUARRIES						*	*	0	0	0	+		
61	SOIL TYPE					+	0	*	*		*	*		
65	SURFACE DRAINAGE				*		*	*	+	+			0	
66	SURFACE WATER				0			*	*	+		*	*	
67	TIMBER CUTTING					0		*						
68	TIMBER VOLUME ESTIMATES					*		*	*					
71	VEGETATIVE COVER TYPE				*	*		*	*	0	0	+	0	0
77	WATERSHEDS								*				*	
78	WETLANDS							*						

KEY = * PRODUCIBLE BY ALL SATELLITES
0 FOLLOW-ON REQUIRED
+ AIRCRAFT REQUIRED

could be produced equally well, if not better, by the advanced satellites. We show for comparison those application areas for which these data items require Follow-On or aircraft for their acquisition.

Finally, for completeness, Table 3-11 shows those data items which require aircraft system capabilities in all applications areas; i.e., those to which none of the current or planned LANDSAT satellites can make a contribution, in our judgement. In addition, aircraft are needed to satisfy some of the data needs in other applications areas, as shown in Table 3-11. Aircraft data are needed for the most part for their higher resolution. We recognize that some of these judgements are challengable. In particular, LANDSAT Follow-On may well be able to replace high altitude aircraft for some of these data items. For others, the size of a feature may sometimes make its detection from satellite feasible. For example, item #46, new construction, can occasionally be detected, even from LANDSAT I. Most often however, state or local agencies need data on new construction at much smaller sites such as at individual dwellings.

3.3.3 Input Data Characteristics

The characteristics of input data for product production are summarized in Table 3-12. The entries in Table 3-12 are based on our understanding of how the various product formats are produced by existing systems and step-by-step extensions of these procedures suitable to an automated EODMS system. We assume that satellite data are used whenever possible. The EODMS systems analysis of Chapter 4 (Section 4.4.1) begins with this set of information.

Table 3-11

Plausible Data Items Which Require Aircraft Remote Sensing For All Application Areas

Number	Data Item	Feasible Platform Altitude		
		Low	Medium	High
1	Aeromagnetic & Gravitometric Surveys	X	X	
7	Aspect	X	X	X
8	Building Condition	X	X	
9	Channelized Stream Length	X	X	X
10	Construction Materials Access	X	X	X
11	Dam Location	X	X	
13	Engineering Geology	X	X	X
14	Erosion of Soil	X		
16	Fish Movement Barriers	X	X	X
27	Forest Stand Age	X		
29	Forest Stand Maturity	X	X	
31	Gaining and Losing Streams	X	X	
35	Historic & Archaeological Sites	X	X	X
41	Land Reclamation Stage	X	X	
42	Location of Individual Trees	X		
43	Mineral Market Access	X	X	
46	New Construction	X	X	
52	Public Facilities Location	X	X	
54	Road Location	X	X	X
57	Slope	X	X	
58	Soil Surface Color	X	X	X
62	Solid Waste Disposal Sites	X	X	
69	Topography	X	X	
70	Tree Crop Species	X	X	
73	Water or Land Radioactivity	X		
74	Water Pollution Outfall Location	X	X	

Table 3-12: Input Data Characteristics for the EODMS Priority Products

Products (and derived by-products)	Platform	Data Type	Resolution	Required Coverage/ Update 65% of 835,530 km^2	Interval Area Covered by Each Image	# of Images Required	Data Update Frequency
forest management map	LANDSAT I, II, C, Follow-On	MSS imagery or CCT's	30 - 80m	2-4 bands of 31% of all images	1 per 34,225 km^2	14	5 years
	High altitude A/C, 1% forest	Color IR photos	10m	1% of forested area	1 per 80 km^2	32	
agricultural management map	High altitude A/C	Color IR photos and/or radar	10m	1% of ag areas	1 per 80 km^2	63	5 years
	LANDSAT Follow-On	MSS imagery or CCT's (27 frames)	30m	2-4 bands of 60% of all images	1 per 34,225 km^3	27	
level I land use map	LANDSAT I, II, C, Follow-On	MSS imagery or CCT's	30 - 80m	Total area	1 per 34,225 km^2	945	5 years
level II land use map A	LANDSAT I, II, C, Follow-On	MSS imagery or CCT's	30 - 80m	Total area	1 per 34,225 km^2	945	5 years
	H/A aircraft	Color photos	10m	10% of total	1 per 80 km^2	1040	
level II land use map B (urban)	High altitude A/C	Color or B&W photos	10 - 30m	1% of total area	1 per 80 km^2	104	5 years
	LANDSAT Follow-On	MSS imagery or CCT's	30m	10% of total area	1 per 34,225 km^2	5	
	Low altitude A/C	Color or B&W photos	2m	0 2% of total area	1 per 2 78 km^2	600	
vegetative cover type map	Low altitude A/C	Color IR, B&W IR, or B&W stereo photos and/or radar	2m	2% non urban and non forested	1 per 2 78 km^2	3900	annual
	High altitude A/C		10m	1% of total area	1 per 80 km^2	105	
	LANDSAT Follow-On	MSS imagery or CCT's	30m	100% of total area	1 per 34,225 km^2	45	
soil map	LANDSAT I, II, C, Follow-On	MSS imagery or CCT's	30 - 80m	100% of total area	1 per 34,225 km^2	45	20 years
forest stand map	LANDSAT Follow-On	MSS imagery or CCT's	30m	31% total area	1 per 34,225 km^2	14	annual
	High altitude A/C	Color IR stereo photos	10m	10% forested areas	1 per 80 km^2	324	
	Low altitude A/C	Color IR stereo photos	2m	2% forested areas	1 per 2.78 km^2	1850	
	Ground survey	Field measurements	---	---	---		
timber volume estimate table	LANDSAT I, II, C, Follow-On	MSS imagery or CCT's	30 - 80m	31% total area	1 per 34,225 km^2	14	5 years
	High altitude A/C	Color IR photos	10m	12 5% forested areas	1 per 80 km^2	405	
	Low altitude A/C	B&W wide angle photos; B&W stereo triplicate photos	2m	2% forested areas	1 per 2.78 km^2	1900	
	Ground survey	Field measurements	---	---	---		
	---	Topographic maps	---				

Table 3-12: Input Data Characteristics for the EODMS Priority Products (continued)

Products (and derived by-products)	Platform	Data Type	Resolution	Required Coverage/ Update 65% of 835,530 km^2	Interval Area Covered by Each Image	# of Images Required	Data Update Frequency
fire measurement map table	LANDSAT C, Follow-On	Thermal channel imagery or CCT's	30 - 80m	31% total area	1 per 34,225 km^2	14	on demand
	High altitude A/C	Radar or thermal IR image	25m	?	?		
	Low altitude A/C	Radar or thermal IR image	10m	?	?		
water impounoment volume table	LANDSAT I, II, C, Follow-On	MSS imagery or CCT's	30 - 80m	100% total area	1 per 34,225 km^2	1	annual
	High altitude A/C	Color or B&W photos	10m		1 per 80 km^2	6	
	Low altitude A/C	Color or B&W photos	2m	.05% total area	1 per 2.78 km^2	150	
lake trophic status maps	LANDSAT I, II, C, Follow-On	MSS imagery or CCT's	30 - 80m	100% total area	1 per 34,225 km^2	1	annual
recreation map	LANDSAT Follow-On	MSS imagery or CCT's	30m	10% total area	1 per 34,225 km^2	5	annual
	Low altitude A/C	Color or B&W			1 per 2.78 km^2	1500	
industrial map	LANDSAT Follow-On	MSS imagery or CCT's	30m	10% total area	1 per 34,225 km^2	5	annual
	High altitude A/C	Color or B&W photos	10m	0.2% total area	1 per 80 km^2	500	
topographic map	Low altitude A/C	Stereo B&W imagery	2m	100% total area	1 per 2.78 km^2	300,000	20 years
	Ground survey	Field checking	---				
slope map	High altitude A/C	B&W and color IR stereo photos	10m	10% total area	1 per 80 km^2	3,000	20 years
	Low altitude A/C	B&W and color IR stereo photos	2m	100% total area	1 per 2.78 km^2	300,000	
	Ground survey	Field checking	---				
	---	Topographic maps	---				
orthophotoquad	High altitude A/C	Stereo B&W imagery	10m		1 per 80 km^2	104,000	5 years
structural geology map	LANDSAT I, II, C	MSS imagery or CCT's	80m	100% total area	1 per 34,225 km^2	45	20 years
	LANDSAT Follow-On	MSS imagery or CCT's	30m	100% total area	1 per 34,225 km^2	45	
	High altitude A/C	B&W IR stereo imagery	10m		1 per 80 km^2	53	
	Low and medium altitude A/C	B&W and color IR stereo imagery	2m		1 per 2.78 km^2	150	
geologic map	Low altitude A/C	Stereo B&W and color IR photos	2m	100% total area	1 per 2.78 km^2	300,000	20 years
	High altitude A/C	Stereo B&W and color IR photos	10m	10% total area	1 per 80 km^2	3000	
	Ground survey	Field mapping					
	---	Topographic maps					

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Table 3-12: Input Data Characteristics for the EODMS Priority Products (continued)

Products (and derived by products)	Platform	Data Type	Resolution	Required Coverage/ Update 65% of 853,530 km^2	Interval Area Covered by Each Image	# of Images Required	Data Update Frequency
surficial materials map	Low and medium altitude A/C High altitude A/C LANDSAT I, II LANDSAT Follow-On, C	B&W, color IR photos B&W, color IR photos Band 5 and 7 imagery or CCT's Band 5, 7, thermal band imagery and CCT's	2 - 3.3m 10m 80 - 120m 30 - 40m	2% total area 100% total area	1 per 2.78 km^2 1 per 80 km^2 1 per 34,225 km^2 1 per 34,225 km^2	3000 3000 45 45	20 years
flood prone areas map	Low altitude A/C ---	Color IR stereo photos Topographic maps	..5 - 2m	10% total area	1 per 1.3 km^2	130,000	5 years
flood inundation area	Low and medium altitude A/C High altitude A/C LANDSAT I, II, C LANDSAT Follow-On	B&W and color IR imagery B&W color IR imagery Bands 5 and 7 imagery and CCT's MSS imagery and CCT's	.4 - 5m .5 - 10m 80m 30m	All -5% total area	1.3 per km^2 1 per 80 km^2 1 per 34,225 km^2 1 per 34,225 km^2	26,000 600 2 2	on demand
earthen dam condition map	Low altitude A/C	B&W and color IR photos	<1m - 2m	0.01% total area	1 per 1.3 km^2	65	on demand
drainage basin map	Low and medium altitude A/C LANDSAT Follow-On	B&W stereo photos MSS imagery and CCT's	0.5 - 2m 30m	10% total area 100% total area	1 per 1.3 km^2 1 per 34,225 km^2	64,000 45	20 years
sinkhole location map	Low altitude A/C ---	Color IR stereo photos Topographic maps	2m - 3.3m	0.2% total area	1 per 2.78 km^2	?	on demand
construction materials availability map	Low altitude A/C LANDSAT Follow-On	B&W stereo photos MSS imagery and CCT's Topographic maps	2m - 3.3m 30m	0.2% total area 100% total area	1 per.2.78 km^2 1 per 34,225 km^2	600 45	20 years
all basic imagery and digital data	---	---	---				

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CHAPTER 4. REGIONAL PROCESSING CENTERS TO PRODUCE THE PRIORITY PRODUCTS

4.1 INTRODUCTION

The previous chapter provides a system output menu (the priority products) and performance specifications (the product characteristics) for the design of an Earth observation data management system.* This chapter attempts to address quantitatively most of the major design issues in systems to produce the priority products.

In this chapter we propose and compare two alternative designs for a regional processing center to produce the priority products for five states. The two designs differ in the methods they employ; one is satellite-based and uses computer processing, while the other employs aircraft data only and traditional photointerpretation for processing.

The chapter's analysis, especially of the satellite-based alternative concentrates on two issues: data management and cost. Under the heading "data management" fall the problems of information processing in the production facility, e.g.:

1. Which and how much data must be acquired (as specified by platform, spectral band, season, etc.)?
2. How much raw data of various types must be stored, for how long, on what medium, and in what format?
3. What data should be kept online (or available to photointerpreters, in the manual case) during processing, and on which storage media?
4. In the digital case, what data structures are appropriate?

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*In this report we define the words, "data management" to mean all the data handling operations (data gathering, storing, processing, and disseminating) that must take place to produce remote sensing-based information products.

5. Is a data base management system necessary to combine data from various sources for processing, and if so, what are some guidelines for its design?

6. What specific processing methods are required, and what equipment and skills do these methods employ?

7. What and how many computer output devices and graphic equipment are needed for final production phases?

Cost issues are similarly varied. We assess cost effectiveness by comparing costs and performance of the two system designs. In addition, we assess cost savings due to the economies of scale and overlaps among disciplines inherent in a multidisciplinary, regional center. Furthermore, we estimate costs of interest to the system designer: capital costs (equipment and buildings) as well as operating costs (satellite, aircraft, and ground data, automated and manual processing, printing, etc.).

The major work of this chapter - the design and analysis of the two systems - is contained in Section 4.4. Sections 4.2 and 4.3 are preparatory investigations which develop design techniques. Conclusions based on this work appear in the conclusions chapter, Section 2.5.

Section 4.2 and Appendix B review production techniques which have been demonstrated (that is, tested in practice) for seven information products similar to our priority products. We compare two production strategies for each product analyzed. One strategy is the method by which the product is produced operationally, while the other method is experimental. The experimental methods, as opposed to the operational ones, usually depend more on remote sensing than on ground surveys and more on machine processing than on manual photointerpretation. For each product so analyzed, we compare capital and production costs, personnel requirements, and performance (as measured by accuracy and timeliness). We describe the methods employed in production in Appendix B.

We were able to acquire sufficient data to do these comparative analyses for seven of the priority products. The products are a timber volume estimate table and six maps: urban and non-urban Level II land use/land cover, soils, vegetative cover type, surface mined land extent and condition, topography, and slope. All but the last two maps can employ either currently available or LANDSAT Follow-On type satellite data, and all can be produced with the aid of a computer.

Section 4.3 and Appendix C present a theoretical method for analyzing computer processing times and costs for producing any product based on digital data, regardless of whether it has yet been produced in practice. The method is based on determining the amount of computation that typical machine processing algorithms require to produce information products from remotely sensed data. Compared to the approach taken in Section 4.2, the theoretical method is more flexible because it can be applied to analyze a wide variety of products. However, it can be used to analyze only machine, not human, behavior, so costs incurred and time spent in manual photointerpretation and other human activities must be analyzed another way. Moreover, it has not been verified in practice. However, together the two approaches in Sections 4.2 and 4.3 form a basis for a fairly comprehensive, flexible, and accurate method of analyzing product production systems.

In Section 4.4 we synthesize and assess the two alternative regional processing center designs. In both cases, we assume that the systems are multidisciplinary and centralized, i.e., that all of the priority products for each of the five states are produced in one regional processing center.

This assumption is based on results of our studies of state agencies and of the magnitude of costs involved in remote sensing data analysis. Generally speaking, processing costs are high, and most small state agencies

can afford only modest additional expenditures for data and equipment acquisition and for training personnel. Thus, a greater number of users might benefit if processing costs are shared. Moreover, to a certain point, economies of scale argue for centralization. Activities such as raw data storage, image enhancement, processing and printing are common to many of the priority products and therefore are better done once than many times. Our analysis in Section 4.4 gives quantitative support for these statements.

On the other hand, there are arguments against taking centralization to the extreme by implementing one national data processing center. Much of remote sensing data processing is still an art, requiring familiarity with the local area to get best results. Moreover, state agencies will have more confidence in information products which they have helped to produce, and products which they have had a hand in designing will be the most useful to them.

Thus, a centrally located, regional processing center seems to offer both efficiency of production and accountability to users. We assume for our convenience that the center serves the five-state EODMS study region.

4.2 OBSERVED COSTS AND PERFORMANCE OF SYSTEMS PRODUCING PRIORITY PRODUCTS

4.2.1 Rationale

To prepare for designing systems to produce the priority products, we first use information on how these products have been produced in the past. Information on tested production methods, costs, and performance provides the most realistic basis for system design and performance analysis.

We found sufficient information for seven of the twenty-seven priority products to compare "operational" methods using traditional photointerpretive techniques with "alternative" ones using LANDSAT data and/or computer technology.

The work in this section and Appendix B helps in system design in a variety of ways. First, observed costs provide a basis in reality for estimating costs for similar activities in a hypothetical regional center. For example, the aircraft data gathering costs for topographic mapping should carry over fairly well to other products (though reduced accuracy requirements may reduce expense). As another illustration, the satellite data processing and multi-stage sampling steps involved in timber volume inventory (on which we have detailed data) correspond to those that might be used in lake trophic status mapping (on which our information is scanty). Extrapolating allows us to specify production steps and estimate costs and performance for the latter product.

Second, detailed lists of processing steps specify which functions have to occur in the center, identify opportunities for resource sharing from overlaps in the production of apparently dissimilar products, and insure that all costs and production times are factored into our estimates. For example, computer processing of satellite data for soils mapping was reported as $4000 for an 800 km^2 study area (4-1) in the document we had. However, the total cost of mapping soils for the area was approximately $52,000

because of salaries and costs associated with the intensive ground truthing required to provide sufficient accuracy.

4.2.2 Results

Table 4-1 compares, for each product analyzed, the operational (traditional) and alternative (nontraditional) production methods.* Included are comparisions of inputs required, data gathering and processing procedures, and cost, time and classification accuracy** estimates.

In the case of the first of the seven products, a timber volume inventory table, Table 4-1 shows that digital interpretation and classification of satellite imagery of forested areas, when coupled with multistage sampling, not only significantly improve the accuracy of timber volume estimation but also reduce costs at least tenfold. The savings are effected by lessening aircraft coverage requirements by taking advantage of synoptic satellite imagery for sample stratification. The increase in accuracy results from determining a good sampling scheme from the statistical theory of sampling.

Level II Land Use/Land Cover mapping also benefits marginally from satellite data and digital processing (on LARSYS) at the 1:24,000 scale. However, at the 1:250,000 scale, costs increase when satellite data are used. On the other hand, nearly all costs of the alternative system at this scale are computer costs, and we calculate that they could be reduced below operational ones if more efficient processors were used. In addition, in this case, accuracy suffers somewhat with satellite data, but speed (as measured by the number of person-years required) is greatly improved.

Soils maps benefit from alternative production techniques by reducing the need for low-altitude photography and by significantly lessening the

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*For more details on costs, a list of references for each column of Table 4-1, and for detailed descriptions of production methods, see Appendix B.

**See Appendix B and Section 4.4.3.2 for a definition of this term.

Table 4-1:

Summary of Comparisons Between Operational and Alternative Methods of Producing Seven Priority Products**

Product	Timber Volume Estimate Table		Level II Land Use/Land Cover Map	
	Operational Method	Alternative Method	Operational Method	Alternative Method
1. Remote Sensing and other Inputs (platform, sensor, resolution, fractional area of coverage)	available low altitude A/C coverage of 100% of state low altitude stereo; 30% (for Missouri) # points (photodots) stereoclassified (22,000 of 214,000 in Missouri) # points (photodots) measured for ground truth (13,200/ 214,000 in Missouri)	LANDSAT, 100%, 80m available high altitude, 100% at 10m low altitude, 1% of 2m ground survey 0.5%	high altitude aircraft black and white aircraft photos 10-30m	LANDSAT CCT 4 band MSS data, 80m M/A* 5% L/A 10% of urban areas
2. Processing Procedures	rough classification on A/C photos sampling on A/C photos sampling on ground	area measurement and rough classification on LANDSAT CCT's fine sampling on low altitude and ground estimation by multi-stage sampling algorithm	photo interpretation of A/C photos into land use classes compile land use data onto planimetric map base	cluster analysis of 10% of image to establish spectral signatures classify into land use classes by maximum likelihood algorithm
3. Production Cost/km^2	\$62.50/km^2 (based on 1 million acres) \$25.25/km^2 (based on 1 million acres)	\$1.63/km^2 (based on 1 million acres)	1:24000-\$11.93/km^2 1:250,000-\$ .88/km^2	1:24,000-\$9.70/km^2 1:250,000-\$1.28/km^2
4. Time Estimates	2 years for 1 million acres	5 months for 1 million acres	32 person-year for 5 state region 830,000 km^2	2.3 person-years for 5 state region
5. Classification Accuracy+	± 20%	± 8.6%	84.9%	80 %

*Key for Table 4-1:

L/A = Low Altitude Aircraft
M/A = Medium Altitude Aircraft
H/A = High Altitude Aircraft
A/C = Aircraft

C = Color
CIR = Color Infrared
B&W = Black and White

**For references and analysis supporting this table, see Appendix B.

+For the applicable definition for an individual product, see its discussion in Appendix B.

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Table 4-1:

Summary of Comparisons Between Operational and Alternative Methods of Producing Seven Priority Products (continued)

Product	Surface Mined Land Extent and Condition Map		Topographic Map	
	Operational Method	Alternative Method	Operational Method	Alternative Method
1. Remote Sensing and other Inputs (platform, sensor, resolution, fractional area of coverage)	high altitude aircraft, black and white or color IR data. 10- 30m 100% of area low altitude aircraft, black and white or color IR photos. 2-3.3m 100% of area	LANDSAT CCT digital data MSS bands 5 and 7 80m 100% of area High altitude A/C coverage of 1% of area	low altitude aircraft stereo black and white photographs. 2-3.3m 100% of area covered	low altitude aircraft panoramic photos, black and white, stereo can also be used. existing line map products. 2-3.3m 100% of area
2. Processing Procedures	photo interpret for extent of surface mines interpret land condition determine change compile on topographic map	perform cluster analysis on spectral values perform pixel-by-pixel classification of spectral reflectance values output map in desired classification scheme	derive contours from photo stereo models compile mappable data cartographic display on map	derive stereo models derive contour from stereo model compile other mappable features produce map
3. Production costs/km^2	$1.81/$km^2$	$1.57/$km^2$	$77.42/$km^2$ @1:24,000	$25.80-$38.71/km^2 @ 1:24,000
4. Time Estimates	3 person months for 4872 km^2	2 person months for 4872 km^2	600 person hour and 6 months printing delay (for 155 km^2)	15-24 person hour for 155 km^2
5. Classification Accuracy	90-95%	80-85%	90^+%	≈90%

Table 4-1:

Summary of Comparisons Between Operational and Alternative Methods of Producing Seven Priority Products (continued)

Product	Level II Soil Map		Vegetative Cover Type Map	
	Operational Method	Alternative Method	Operational Method	Alternative Method
1. Remote Sensing and other Inputs (platform, sensor, resolution, fractional area of coverage)	low altitude aircraft stereo black and white photos. 2-3.3m	LANDSAT CCT MSS data 4 bands. 80m High altitude A/C and low altitude A/C need to verify.	low and medium altitude aerial photography B&W/C/CIR -2m resolution total coverage of area	LANDSAT-MSS Digital and Image Skylab (if available) RB-57 and U-2 photography C/CIR L/M/H A/C C & B/W 80m - 2m
2. Processing Procedures	stereoscopically review area delineate soil types on aerial photos of area delineate slopes and erosion areas field check edit and compile map	train computer to recognize soil class spectral signatures point-by-point classify CCT LANDSAT scene output classified soil map	visual interpretation of photos, intensive field survey on ground preliminary survey by automobile	conventional photo-interpretation and interactive digital processing techniques
3. Production Cost/km^2	\$1.88/km^2	\$65.01/km^2	\$3.35/km^2@1:250,000 \$29.63/km^2@1: 24,000	\$1.17/km^2@1:250,000
4. Time Estimates	9 person-year per 800 km^2@ 1:24,000	4 person-year per 800 km^2@ 1:24,000	23 man-years @ 1:250,000 54 man-years @ 1:24,000 (10% area sampled)	4 person-years @ 1:250,000
5. Classification Accuracy	99%	90% (cultivated or bare soil) lesser accuracies in vegetated areas	95^+%	85^+%

Table 4-1:

Summary of Comparisons Between Operational and Alternative Methods of Producting Seven Priority Products (continued)

Products	Slope Map	
	Operational Method	Alternative Method
1. Remote Sensing and other Inputs (platform, sensor, resolution, fractional area of coverage)	existing topographic maps. 1:24,000 scale 2m - 3.3m 75% of covered area	as in operational system
2. Processing Procedures	interpret topographic map to derive slope zones compile slope zones overlay on planimetric map base.	analog process topographic map semi-automatically based or differences in spacing of adjacent contour lines compile on planimetric base
3. Production Costs/km^2	$6.02/$km^2$@ 1:24,000	$12.24/$km^2$@ 1:24,000
4. Time Estimates	242 person/hour/map (155 km^2)	160-180/hours/map (155 km^2)
5. Accuracy	60-68%	80^+%

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ground survey requirements. The alternative method is slightly less accurate than the operational method, but it is faster.

Vegetative cover maps produced by satellite are approximately one-third as expensive as those produced operationally from high-altitude aircraft imagery. However, they suffer somewhat from lack of detail and accuracy. This disadvantage is mitigated by increased ability to update frequently.

Surface mined land extent and condition maps show insignificant marginal cost improvement with alternative technologies, and they lose accuracy.

The last two products analyzed, topographic and slope maps at 1:24000 scale, do not benefit from earth resources (or any other current) satellite data. However, they were included in this analysis because detailed cost data on these products were available. Moreover, they exemplify one important type of information product producible from remote sensing and needed by state agencies--the product that contains information so detailed that low and medium altitude aircraft must be used for data gathering.

Topographic and slope maps can benefit from machine-aided processing. A currently experimental, automated contouring system will greatly speed topographic map production if it is successful, cutting costs by as much as two-thirds. An automated system for slope map production* is more expensive than the current manual technique, which simply involves identifying areas with a given degree of slope by eye directly from a topographic map. However, it is much more accurate than the manual method.

It must be noted that the figures in Table 4-1 are production costs.** They do not include salaries of administration and support staff, amortized charges for buildings, etc.

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*See Appendix B

**Definitions for this term vary somewhat with the source. See Appendix B for more detail on the costs included.

In summary, we have investigated a range of products and have seen mixed benefits in using current LANDSAT data and automated processing techniques.

One product, the timber volume estimate table, benefits in all three of the categories of cost, accuracy, and speed. It is produced over the large homogeneous areas (forests) most directly suited to satellite applications. Three other products: land use, vegetation, and soils maps, also show good potential for satellite application, although they benefit only in cost and speed while suffering somewhat in accuracy. These products are produced over large, but less homogeneous, areas and display many more classes than does the map of timber density constructed in producing the timber volume estimate. Thus, the three products depend more heavily on aircraft and ground survey inputs.* Finally, three products (surface mined land, topographic, and slope maps) demonstrated little or no potential for satellite application. These products are either produced over small, isolated areas (as in the case of surface mined land maps) or they contain large amounts of information not derivable from satellite. However, two of these last three products (topographic and slope maps) can benefit significantly from automated production methods.

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*Remember that these results were achieved with experimental, not operational, processing techniques and with LANDSAT data. We expect better accuracy performance with tested processing algorithms and LANDSAT Follow-On data.

4.3 ESTIMATING COMPUTER IMAGE PROCESSING TIMES AND COSTS

In this section and Appendix C we develop a theoretical method for estimating machine computation times and costs for applying common image processing algorithms to digital remotely sensed data. The method combines two independent estimation techniques.

The first technique employs simple interpolation of costs incurred by a past user of LARSYS. This method is accurate, in that it takes account of all computation costs, including system overhead. However, it is inflexible, because it applies only to LARSYS software and to the IBM 360/67 on which the user's programs were run. The second technique determines computation times and costs theoretically by calculating computational loads put on a computer by various image processing algorithms. By contrast with the first scheme, it can be applied to any serial computer. However, because it fails to account for "overhead" computational costs,* it is inaccurate when used alone.

Combining the two techniques allows us to take overhead into account, as the first scheme does, while retaining the second technique's flexibility. This section briefly reviews this work, while details appear in Appendix C.

4.3.1 Estimation by Interpolating from Observed Costs and Times

A past LARSYS user has supplied us with tables of costs he incurred in producing Level II Land Use maps.(4-2) Table 4-2 lists these costs. Note that they depend on the number of pixels processed, the number of classes ("clusters") into which the data is classified, the types of processing used, and the cost of a CPU minute of processing time on the LARSYS computer. In 1973 when the costs listed in Table 4-2 were incurred, the CPU minute cost was $6.00, while as of May, 1976, it was $4.83.(4-3)

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*Examples of system overhead costs in image processing are those involved in running the computer's operating system or in man-machine interaction.

Table 4-2: LARSYS Processing Costs For LANDSAT Data*

Image Processing Operation		Cost of Operation For One LANDSAT Image***
LANDSAT/LARSYS Format	$ 65 + 8 (MP)**	$ 125
Geometrically Correct	$125 + 525 (MP)	$ 4094
Overlay	$600 + 1500 (MP)	$11940
Total Preprocessing Cost		$16159
Clustering (approx.)	$500	$ 500
Classification by Maximum likelihood 4 channels; one iteration	30 clusters	6563
	40 clusters	8750
	50 clusters	10928

*The LARSYS costs presented in this table were charged for processing done in December 1973(4-2). The costs are not official cost figures issued by LARS.

**MP = million pixels.

***One LANDSAT frame contains 7.56 million pixels.

As it is, the table can be used to estimate both LARSYS processing costs (based on the old $6.00 per CPU minute charge) and processing times in CPU minutes. From this processing time estimate, we can project costs for any other LARSYS per CPU minute charge--for example, the more recent one of $4.83.

For example, Table 4-2 presents costs calculated for an entire LANDSAT image (7.56 million pixels) based on the cost equations in the Table. We can convert from these costs to processing times if we make the following assumptions: (1) The "per run" charges given in Table 4-2 are assumed to represent input/output and special overhead costs. (2) The "per million pixel" charges are assumed to represent CPU costs. We can estimate CPU times by dividing the total "per million pixel" charges by $6.00/CPU minute, the cost per CPU minute on which Table 4-2's equations are based.

Extrapolating to any other per-CPU-minute charge is then simple if we assume that the fixed costs listed in Table 4-2 remain unchanged. The total cost of an algorithm is then its fixed costs plus the product of the number of CPU minutes it consumes and the new per CPU minute charge. For example, geometric correction of a LANDSAT image at the old $6.00/CPU minute rate cost $125 + $525(7.56) or $4094. Under our assumptions, the processing time required is $525(7.56/$6.00) or 670 CPU minutes. Thus, if the new processing charge is $4.83/CPU minute, this algorithm would cost $125 + 670($4.83) or about $3360. to run the same data.

4.3.2 Analytic Estimation of Processing Times and Costs

In this section, we briefly review an analytic estimation method that we have developed. The method estimates computer image processing costs throughput performance for any serial computer system and is based on

calculating the computational load* involved in processing.

We begin by determining the computational requirements** of algorithms commonly used to machine process remotely-sensed data from functional descriptions*** of each algorithm. Table 4-3 lists these requirements, which depend on the algorithm, the number of bands and pixels of image data to be processed, and certain computer memory size parameters. See Appendix C for an explanation of how they are developed.

The second step is to calculate the cost (in both time and money) of each of these algorithms on common computer systems. Table 4-4 presents the execution times for each basic operation on three example computers+. (4-4,4-5)

Multiplying the number of each operation employed in an algorithm (see Table 4-3) and the execution time for that operation and then summing times for all operations gives a total computation time per algorithm on a given computer. Finally, the product of this computation time and an estimated per CPU minute charge gives the cost of each algorithm. Table 4-5 presents these time and cost estimates.

The final step is to use the mix of algorithms necessary to produce an

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*The "computational load" means the number of each type of basic computer operation (e.g. add, multiply, or compare) required to accomplish a processing task.

**By an algorithm's "computational requirements", we mean the number of computer operations (add, multiply, etc.) required to perform an algorithm.

***By an algorithm's "functional description," we mean a list of steps describing the algorithm.

+Computers for illustration only.

Table 4-3: Algorithm Computational Requirements

Task	# Moves (1 byte within main memory)	# Disc Accesses (Read/Write N lines' data)	# Adds	# Multiplies	# Compares
Reformat CCT's	$2BN_p$	5460/M	--	--	--
Determine Resample Coordinates a) Linear Transformation	$4N_p$	2340/M	$2N_p$	$4N_p$	--
b) Affine Transformation w/Bilinear Interpolation (30 triangles, 20x20 Interpolation Grid)	$4N_p$	2340/M	$94,000 + 18N_p$	$56,000 + 10N_p$	19,000
c) Least Squares Fit w/Bilinear Interpolation (Degree = N, 20x20 Interpolation Grid)	$4N_p$	2340/M	$2N^4 + 31N^3 + 3292N^2 + 9799N + 4828 + 18N_p$	$2N^4 + 15N^3 + 1849N^2 + 5489N + 3623 + 10N_p$	--
Resample a) Nearest Neighbor	$2BN_p$	4680/M	$4N_p$	--	$2N_p$
b) Bilinear Interpolation	BN_p	4680/M	$(6 + 3B)N_p$	$(1 + 4B)N_p$	--
c) Cubic Convolution	BN_p	4680/M	$(28 + 15B)N_p$	$(20 + 20B)N_p$	--
Contrast Enhancement	$2BN_p$	4680/M	128B	128B	14,161B
Classification: a) Gaussian Maximum likelihood (C classes)	CN_p	2925/M	$[C(B^2 + B + 3)-1]N_p$	$(B^2 + B + 1)CN_p$	$(C-1)N_p$
b) Clustering (C classes, I iterations)	ICN_p	2925I/M	$BI[(C + 3)N_p + 3C + 1] + \frac{C(C-1)}{2}(4B^3 + 3)$	$BI[5C + (C + 1)N_p + 1] + \frac{C(C-1)}{2}[4B^3 + 2B^2 + 1]$	$(C-1)N_pI$

Notes: a) B = # of bands (4 for current LANDSAT

b) N_p = # of pixels (7.6×10^6 for one LANDSAT image)

c) I = # of iterations

d) $M = \dfrac{\text{main memory size (bits)}}{1.05 \times 10^5}$

e) 4M = # of imagery lines able to be stored in main memory

Table 4-4: Execution Times for Four Basic Operations on Example Computers (in Microseconds)*

Computer System	(Effective) Move Time	Add Time	Multiply Time	Compare Time
IBM 370/195	0.0945	0.11	0.16	0.11
Univac 1108	0.1667	1.875	2.62	1.875
IBM 360/67	0.0938	5.4	6.8	5.4

*These figures are from (4-4, 4-5).

Table 4-5: Algorithm Processing Time and Costs for One LANDSAT IMAGE

Task	Algorithms	IBM 370/195	Univac 1108	IBM 360/67
		CPU Time* / CPU Cost		
Reformat CCT's	Reformat	5.72 sec. / 2.72	10.12 sec. / $1.80	5.67 sec. / $0.52
Determine Resample Coordinates	1. Linear Transformation	9.37 sec. / $14.29	112.95 sec. / $20.16	248.48 sec. / $22.69
	2. Affine transformation w/Bilinear Interpolation	30.02 sec. / $14.29	459.92 sec. / $82.10	1,256.30 sec. / $114.74
	3. Least Squares Transformation w/Bilinear Interpolation (N-4)	30.03 sec. / $14.30	459.95 sec. / $82.10	1,256.29 sec. / $114.84
Resample	1. Nearest Neighbor	10.73 sec. / $5.11	95.41 sec. / $17.03	251.32 sec. / $22.95
	2. Bilinear Interpolation	38.50 sec. / $18.33	598.62 sec. / $106.85	1,616.20 sec. / $147.61
	3. Cubic Convolution	197.57 sec. / $94.07	3,242.40 sec. / $578.77	8,761.11 sec. / $800.18
Contrast Enhancement	Enhance	5.73 sec. / $2.73	10.23 sec. / $1.82	5.99 sec. / $0.55
Classification (37 classes)	1. Maximum Likelihood	1,707.94 sec. / $785.09	28,075,87 sec. / $5,011.54	76,257.86 sec. / $6974.02
	2. Clustering (15 iterations)	5,615,34 sec. / $2,673.83	87,785.32 sec. / $15,669.68	238,307.45 sec. / $21,765.41

*The exact results of our calculations are presented here so that the interested reader may check the method. In applying the method, one should limit himself to two or three significant figures, as we have done in Section 4.4.

information product from raw data to specify a per product computational load, and thus to calculate that product's computation speed and cost. For example, one algorithm sequence which might be used to process LANDSAT data for 37-category Level II Land Use/Cover Maps is illustrated in Figure 4-1*. Table 4-6 lists processing costs estimated by this method for processing a full (four-band, 7.56 Million pixel) LANDSAT image into a 37-category Level II Land Use/Cover Map on an IBM 370/195. The computation time estimate for this processing sequence on this computer is 560 CPU minutes.

Appendix C describes this analytic method in considerably more detail. In addition we use the method there to estimate processing costs on LARSYS. Comparing our estimate with true LARSYS costs (derived by the technique of Section 4.3.1) shows that the estimate is 14% low for one example product. This is to be expected; our functional descriptions do not account for system overhead. In addition, our processing cost does not include salaries for the consultants and other staff required to use effectively a specialized data processing system.

4.3.3 A Combined Estimation Method

Both methods thus have faults. The first applies only to one computer, while the latter ignores overhead. In this section we combine the two techniques to incorporate the strengths of each. The combined procedure is:

1) From the analytic estimates of Table 4-3, compute the number of each type of computer operation (e.g. add, multiply, etc.) required to perform a given algorithm.

2) Use the method of Section 4.3.2 to determine the percentage of total CPU time devoted to each type of operation on the IBM 360/67.

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*Experiments in which LANDSAT data was processed using algorithmic sequences similar to Figure 4-1 (e.g. ref. (4-6)) have not yet achieved Level II accuracy. The sequence does, however, provide an illustrative example of a typical processing technique.

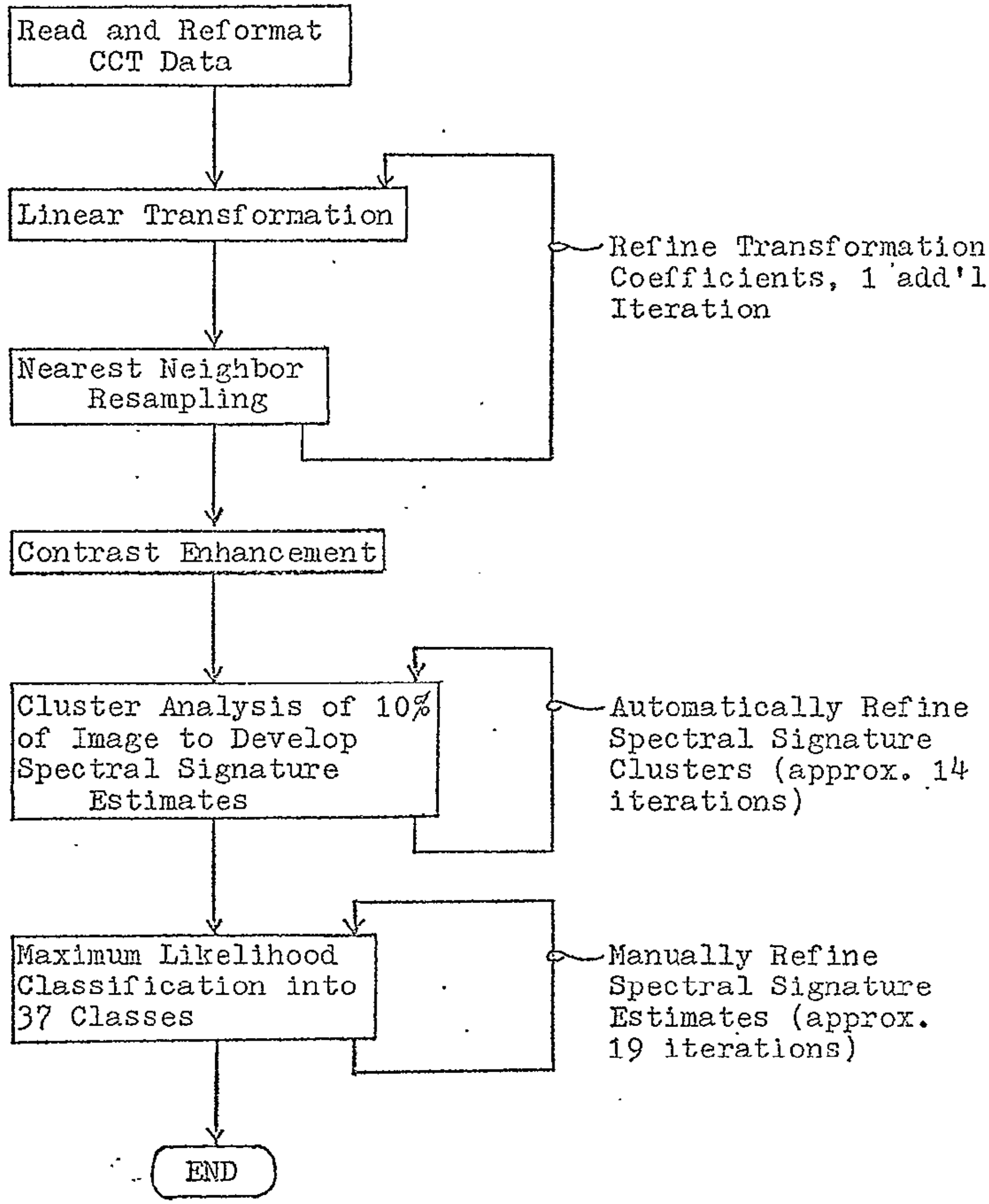

Figure 4-1: Processing Sequence for Level II Land Use/Cover Maps

Table 4-6: Costs for Processing One LANDSAT Image For Level II Land Use/Cover

Cost per CPU minute = $28.57 for IBM 370/195 system.

Reformatting	$ 2.72
Geometric Correction 2 Iterations	19.14
Contrast Enhancement	2.73
Cluster Analysis of 10% of Image 37 clusters, 15 iterations	267.40
Maximum Likelihood Analysis 37 classes, 20 iterations	15,702.00
Total CPU Costs (approx.)	$15,990.00

3) Using the first technique, determine the total CPU time required to perform the algorithm on the IBM 360/67.

4) Using the percentages of total time found in 2) with the total time found in 3), evaluate the CPU time attributable to each computer operation type.

5) From the time estimates of 4), determine the number of each operation type actually required to perform the algorithm.

The method scales the number of each operation required upward to account for system overhead. The scaled numbers of each operation type may then be used to determine the time to perform each algorithm on any serial computer. This combined method is the one which we apply in designing the satellite-based regional processing center in Section 4.4.

*See Appendix C for more details.

4.4 TWO DESIGNS FOR A REGIONAL CENTER TO PRODUCE THE PRIORITY PRODUCTS

This section contains the major work of the chapter - the design and assessment of regional centers to produce the priority products. Two goals dominate this effort: (1) to assess costs, economies of scale, and cost effectiveness of satellite data and digital processing in producing the priority products, and (2) to lay out the satellite-based digital processing system in some detail and assess its data management problems quantitatively.

The reader must keep in mind that the cost and performance figures we present here are merely estimates, made as accurately as possible but nevertheless subject to error and sensitive to our assumptions. A detailed system design and error analysis is beyond the scope of this work. However, we expect that the conclusions and recommendations based on this work will stand despite any reasonable variations in numerical results.

Section 4.4.1 contains the design of the satellite-based system, a calculation of its production costs, and the data management discussion. For comparison, Section 4.4.2 presents a system design based on interpretation of aircraft data and estimates of its production expenses. To evaluate cost effectiveness, Section 4.4.3 compares the total costs (including overhead) and performance of the two systems. Section 4.4.4 presents an assessment of the economies of scale realized by centralizing processing along both disciplinary and geographic lines in the regional center.

4.4.1 A Design Based Primarily Upon Digital Processing of Satellite Data

To design the satellite-based center, we calculate its digital data load; specify and cost the computer system; lay out and cost supporting aircraft and ground truth missions; estimate production times; and summarize and total all production costs. We also outline the major features of the center's data base management system.

4.4.1.1 Calculation of Digital Data Processing Requirements

In this section, we describe the digital data processing required to produce the priority products from satellite data. We assume that only satellite-derived data are digitally processed; that is, that supporting aircraft and ground survey information do not significantly increase the digital processing load. In addition, we exploit all possible overlaps in processing among the satellite-based products.

Identifying these overlaps thus becomes significant. Toward this end, this section seeks to answer two questions: (1) What classes of satellite-derivable information are displayed by the priority products, viewed as a whole? (2) Is there a subset of the menu of priority products which contains all this satellite-derived information? Answering the first question allows us to specify into how many classes the satellite data must be classified - a significant determinant of classification cost. Answering the second is equivalent to identifying overlaps in processing requirements among products, because if a subset of the total product menu contains all satellite-derivable information, then only these products must be derived from raw satellite information. The other products can be derived from these "fundamental" ones without further processing of raw satellite data. Thus specifying a list of "fundamental" products reduces our processing task to a minimum.

We have been able to answer both of the questions posed above. First, there appear to be forty-one "basis" classes of information derived from classifying raw satellite imagery displayed on the five-state region's priority products. Second, four "fundamental" products display all "basis" classes in sufficient detail and with sufficient coverage so that all of the other priority products can derive their satellite-based information from these four.

Table 4-7 lists forty-one satellite-derived object classes displayed on satellite-derived products. We term these the "basis" classes. Satellite data analyzed into these classes, coupled with judicious use of aircraft imagery and manual ground-truthing, form an information base from which the eighteen priority products based on machine-interpreted satellite data* could conceivably be derived.

The "basis" classes are formulated on two principles. First, to be conservative and not overestimate the capability of satellite data to provide information, we choose only those classes most likely** to be derivable from satellite data by machine classification. Second, all eighteen priority products based on classified satellite imagery display either some of the basis classes, aggregations of some of these classes, or finer divisions of a given class. We assume that any distinctions finer than those made by the basis classes (e.g. from Forest Type (a basis class) to tree species) would be made from data gathered from aircraft or ground survey.

With this background, we can verify that four "fundamental" products contain all satellite-derived information displayed by all eighteen priority products based on classified satellite imagery. These products are:

1) Level II Land Use Maps

2) Vegetative Cover Maps

3) Timber Density Maps (a satellite-derivable input to the Timber Volume Estimate Table)

4) Lake Trophic Status Maps

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*Seven priority products use only aircraft imagery. Two others - geologic maps and basic imagery, use raw satellite data only. The remaining eighteen can employ classified satellite data.

**These classes have been derived from satellite data in experiments. In fact, more crop, natural vegetation, forest type, and lake trophic classes have been derived. Thus, the forty-one classes are our conservative estimate of the number derivable operationally.

Table 4-7: Satellite-derived "Basis" Object Classes*

Level II Land Use

Class	(USGS 964)	Descriptor
1	11	Residential
2	12	Commercial and Services
3	13	Industrial
4	14	Transportation, Utilities, Communications
5	15	Industrial and Commercial
6	16	Mixed Urban and Built Up
7	17	Other Urban
8	23	Confined Feeding
9	51	Streams and Canals
10	54	Lakes and Impoundments
11	73	Sandy Areas Not Braches
12	74	Bare Exposed Rock
13	75	Strip Mines, Gravel Pits, Quarries
14	76	Transitional Areas
15	77	Mixed Barren Land
16	--	Other

Vegetative Cover Map**

Class	(USGS 964)	Descriptor
22	--	Crop Type 1
23	--	Crop Type 2
24	--	Crop Type 3
25	--	Crop Type 4
26	--	Crop Type 5
27	--	Forest Type 1
28	--	Forest Type 2
29	--	Forest Type 3
30	--	Forest Type 4
31	--	Forest Type 5
32	--	Nat Veg Class 1
33	--	Nat Veg Class 2
34	--	Nat Veg Class 3
35	--	Nat Veg Class 4
36	--	Nat Veg Class 5

Lake Trophic Status

Class	USGS 964	Descriptor+
17	--	Lake Trophic Class 1
18	--	Lake Trophic Class 2
19	--	Lake Trophic Class 3
20	--	Lake Trophic Class 4
21	--	Lake Trophic Class 5

Timber Volume Estimate (Density Map)

Class	USGS 964	Descriptor
37	--	Density Class 1
38	--	Density Class 2
39	--	Density Class 3
40	--	Density Class 4
41	--	Density Class 5

*Adapted where noted from Anderson, USGS Circular 964, (4-7).
**See Appendix B for a discussion of the number of classes assumed
+EODMS staff estimates that five trophic status classes are derivable

A check of the priority product characteristics (Table 3-4) shows that they display all forty-one basis classes.* Together, they cover at least the area covered by any of the remaining fourteen products based on interpreted satellite data. Moreover, they are updated at least as frequently as the others. Thus, we can say that the four "fundamental" products alone determine the satellite data processing load.

We can now begin to specify the raw data required yearly by the center and the yearly processing load (that is, the number of images to be classified and the number of classes into which each image must be classified), characteristics determined solely by the four "fundamental" products. Four characteristics of each product determine processing requirements:

1) The number and type of classes it displays.

2) The area it covers

3) Its update frequency.

4) The seasonal schedule of its imagery acquisition.

In addition, a fifth factor, inherent not in the products but in the imagery, also determines processing required. This is the probability that a given image is cloud-free. We discuss these five factors below.

First, the number and type of classes uniquely displayed by each fundamental product can be determined from the headings in Table 4-7, the list of "basis" classes. Level II Land Use Maps display - by definition - thirty-seven classes. (4-7) Of these, twenty-eight are relevant in the five states. However, only sixteen of these are nonvegetative classes, and vegetative classes are displayed in at least as much detail on vegetative cover maps. Thus, the land use maps

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*Table 4-7 indicates which products display which basis classes. The classes actually displayed on the final products may be finer subdivisions of the basis classes, especially on the Vegetative Cover Map. However, the basis classes can be rederived by aggregation.

display sixteen unique, satellite-derivable classes. Using similar reasoning the numbers of basis classes displayed on the other fundamental products are: Vegetative Cover - fifteen,* Timber Volume Density - five, and Lake Trophic Status - five.

In addition to the number of classes displayed, a second determinant of processing load is the area covered by each product. To estimate the area involved with each product, we extend land cover statistics for Missouri throughout the five-state region.** The percentage coverages and areas involved are (4-9):

	Missouri	5-state (km^2)
Cropland	38%	317,300
Pasture and Rangeland	19%	158,650
Forest	31%	258,850
Urban	4%	33,400
Water	0.5%	4,175
Federal Land	4%	33,400
Other	3.5%	29,225
	100.0%	835,000
Flood Prone	20%	167,000

From these statistics, we see that Level II Land Use Maps containing the sixteen nonvegetative classes are needed over about 10% of the area; Vegetative Cover, 90%; Timber Volume, 31%; and Lake Trophic Status, 0.5%.

We specify the third determinant, update frequency, from our analysis of user needs. Our studies indicate that five years is a sufficient update

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*Note that on the final copy of a Vegetative Cover Map, more than fifteen classes may be displayed. We assume, based on past experience (4-8) that only fifteen are satellite-derivable, and that finer divisions of these classes would be done by aircraft and ground survey.

**This is equivalent to assuming that Missouri's land use statistics are typical for the five states. This may not be true, but it should not introduce significant error in our design, since our cost numbers appear to be relatively insensitive to reasonable variations in these figures.

frequency for two of the fundamental products, Level-II Land Use Maps and Timber Volume Density Maps. Thus, a regional center must produce these products for one-fifth of the five-state region annually. The other fundamental products, Vegetative Cover Maps and Lake Trophic Status maps, must be updated annually.

Season of imagery acquisition, the final product characteristic on our list, is determined by the nature of the product. To produce the four satellite-derived fundamental products, winter, spring, and summer LANDSAT imagery must be analyzed. Level-II Land Use Maps require winter imagery to delineate urban and "built-up" land classes. The other three products use spring or summer imagery.

One remaining consideration is the acquisition of cloud-free imagery. EROS statistics show that twenty-five per cent of 901 LANDSAT images taken over sample areas in each of the five states had ten percent cloud cover or less.* A single LANDSAT satellite makes twenty passes over an area per year; on the average, five of these produce sufficiently cloud-free imagery. Our fundamental products require at least one cloud-free image (or a mosaic of cloud-free areas from more than one) in every season but Fall. A single LANDSAT satellite is therefore likely to provide the coverage required in winter, spring, and summer without requiring excessive mosaicing to produce "cloud-free" imagery, and two-satellite coverage improves the situtation further.

This information allows us to specify a total satellite input data load for the regional center. The amount of processing required is determined by the fundamental products' coverage areas and update frequencies.

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*EODMS staff made this observation from data supplied by USGS's Applications Assistance Center at Rolla, MO. Probability of cloud cover showed no strong season dependence.

For example, we are assuming that only thirty-one percent of the five-state region is forested. Moreover, due to its five-year update frequency, only one fifth of the region's Timber Volume Density Maps must be produced annually. If orbital overlap and edge effects are included, forty-five LANDSAT images are required to cover the five-state region. Thus, 31% of one-fifth of the forty-five images covering the region must be processed yearly for timber volume density. (Note: this assumes that the location of all forests are known a priori. They will either be known before processing begins, or since all forty-five covering images must be processed to produce vegetative cover maps, forest, lake, and urban areas can be located on the imagery during this processing for further processing into the other three fundamental products.)

The total imagery input, using similar reasoning, is:

Vegetative Cover Maps	100% of 90 images (full coverage; spring & summer)
Timber Volume Estimate	31% of 9 images (forested areas; summer)
Level-II Land Use	10% of 9 images (urban and nonvegetated areas; winter)
Lake Trophic Status Map	0.5% of 45 images (lakes; summer)

This input data, coupled with the list of processing techniques necessary to produce the priority products, specifies an annual data processing load, which is summarized in Table 4-8.

Including overlaps in usage, only ninety-nine distinct images are required to produce the fundamental products. Moreover, of the ninety used to produce Vegetative Cover Maps, experience shows only LANDSAT bands 5 and 7 would provide useful data.(4-8) By overlaying bands 5 and 7 from spring and summer imagery, forty-five frames of composite imagery result. On this basis, the regional center must analyze only forty-five "equivalent images"* per year for this map. In addition, since the Vegetative Cover Map displays fifteen

*An equivalent image is a block of image data equal in size (number of pixels and number of bands) to a single satellite image.

Table 4-8: Annual Regional Center
Digital Data Processing Load

Preprocessing:

Reformat 99 images
Geometrically Correct 99 images
Overlay Bands 5 and 7 of 45 pairs of images

Cluster Analysis: (Note that to establish spectral signature estimates, only selected portions of each image need be clustered)

Land-II Land Use	9 winter images
Vegetative Cover Map	45 composite images
Timber Volume Inventory	9 composite images
Lake Trophic Status	1 composite image

Maximum Likelihood Analysis:

Land-II Land Use	10% of 9 images into 16 classes
Vegetative Cover Map	100% of 45 images into 17 classes
Timber Volume Inventory	31% of 9 images into 5 classes
Lake Trophic Status	0.5% of 45 images into 5 classes

satellite-derived vegetative cover classes plus two others - lakes and urban areas (to identify the data which must be processed further into other products) - these images must be classified into seventeen classes.

4.4.1.2 Choice of a Suitable Computer; Computer Production Time and Cost Calculations

4.4.1.2.1 Production Times and Costs on LARSYS

We employ the combined estimation scheme described in Section 4.3.3 to estimate production times and costs on any processor. This scheme requires that we begin by calculating costs and times on LARSYS using the method of Section 4.3.1.

To calculate the cost of the processing listed in Table 4-8, we assume: 1) that the costs associated with partitioning data are small; 2) that processing one "equivalent" image costs the same as processing one actual image with the same number of pixels; 3) that the cost of one iteration of Maximum Likelihood analysis varies linearly with the number of object classes desired. Under these assumptions, LARSYS preprocessing costs are $955,000,* the cost of clustering portions of sixty-four images is $32,000, and the cost of one iteration of maximum-likelhood analysis is $174,000.

As described in Section 4.3.3, the purpose of calculating these costs is simply to find the number of CPU minutes of processing required on LARSYS. Using the procedure described in that section, and assuming a single maximum likelihood iteration produces sufficient accuracy, we find that to process the fundamental products requires 186,000 CPU minutes annually on the IBM 360/67** Assuming 140 CPU hours are available per month, however, there are

*Assuming the old $6.00/CPU minute rate. As section 4.3.1 notes, this rate has decreased.

**The computers discussed in this section are for illustration only; no recommendations are intended.

only 100,800 CPU minutes available per year. Thus the IBM 360/67* is too slow to be used at the regional center; faster computers must be considered.

4.4.1.2.2 A Suitable Processor

Because the IBM 360/67 would be overloaded by the regional center's fundamental product processing requirements, in this section we perform calculations based on computers able to handle the processing load assuming that either current 80 meter resolution LANDSAT data or 30 meter resolution LANDSAT Follow-on data is used.

Using the method of Section 4.3.3, we first evaluate the processing times and costs on the CDC 7600,* a large scientific computer which supports time-sharing applications. If we again assume that a single maximum likelihood (ML) iteration produces sufficient accuracy, the yearly processing requirement for the fundamental products using eighty meter resolution data is $45,800 in input/output costs plus 3242 CPU minutes. Assuming 140 CPU hrs. per month, this corresponds to 3.2% CPU utilization. If, on the other hand, we assume the number of maximum likelihood iterations required to achieve acceptable accuracy rises exponentially with the number of product classes (see Appendix C) , then the annual processing requirement is $45,800 in input-output costs plus 4965 CPU minutes; this corresponds to 4.9% CPU utilization. Clearly, in either case, this computer will be underutilized. That is, the CDC 7600 is too large a computer to use only to produce the fundamental products for the five-state region from eighty meter resolution LAND SAT data.

The Univac 1110 is another computer which supports time-sharing

*The computers discussed in this section are for illustration only; no recommendations are intended.

applications and is midway in speed between the IBM 360/67 and the CDC 7600. The yearly processing requirement for the fundamental products on the Univac 1110, assuming a single ML iteration produces sufficient accuracy, is $45,800 in input/output costs plus 26,990 CPU minutes. Assuming the number of ML iterations required rises exponentially with the number of product classes,* the yearly basis product processing requirement is $45,800 plus 44,850 CPU minutes. These two cases correspond to 26.8% CPU utilization and 44.5% CPU utilization respectively.

These are reasonable utilization figures for the EODMS computer. The Univac 1110 will be significantly utilized in producing the priority products, but fully fifty-five percent of the computer's capacity will be available for EODMS data base management activities, processing of "on-demand" products, administration, and research. Thus Univac 1110 can be used for processing eighty meter resolution LANDSAT imagery into the fundamental products. Using the method of Section 4.3.3, the cost per CPU minute is $10.48 for the 1110. Assuming multiple ML iterations are required (as specified by the exponential function in Figure 4.4), the total yearly processing cost to produce the basis products is $516,000.

A similar analysis can be made of the processing requirements for deriving the fundamental products from the thirty meter, seven band satellite data of the proposed LANDSAT Follow-On mission. In particular, assuming use of only four bands, the major effect on EODMS would be that each 185 km square-image would now include 53.9 million pixels, as compared to the 7.56 million pixels per frame of current LANDSAT eighty-meter resolution data.

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*The exponential curve in Appendix C implies that four iterations are necessary to classify the 16-class Level II Land Use and 17-class Vegetative Cover Maps, while the five-class Lake Trophic Status and Timber Density maps require two iterations of the maximum likelihood classifier.

To process the Follow-on data load using the Univac 1110 entails annual processing requirement of $60,000 plus 271,500 CPU minutes for a single ML iteration. If multiple ML iterations are required, the annual processing requirement for the basis products is $60,000 plus 407,700 CPU minutes. Clearly either case overtaxes a single Univac 1110. If, out of stubbornness, we acquire three or five 1110's to do our processing in the two cases, the annual production costs (at $10.48 per CPU minute) are $2,905,000 and $4,333,000 for the single and multiple ML iteration cases, respectively.

If, on the other hand, EODMS employs a CDC 7600 to handle the increased processing load, the annual processing requirement for the single ML iteration case is $60,000 in input/output costs plus 32,610 CPU minutes, corresponding to 32.4% utilization. For the multiple ML iteration case, we calculate $60,000 plus 45,140 CPU minutes, corresponding to 44.8% utilization. At $19.52 per CPU minute for the CDC 7600, the total annual computation costs for product production in the five states are $696,500 and $941,000 for the single and multiple iteration cases respectively.* Comparison of the costs for the two computers illustrates the economy of scale in matching a single computer to the EODMS data load.(See Section 4.4.4)

Our examples illustrate the importance of maintaining flexibility in the early stages of EODMS development. If EODMS initially invests in overlarge computer capacity, much of this capacity will be wasted until the data load "catches up" with the available processing power. If, on the other hand, EODMS commits itself at an early date to the use of small computers,

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*Recall that these computation costs allow for overhead such as operators' salaries, costs of peripheral devices, etc. The annual lease cost for a CDC 7600 central processor is $532,000.(4-4)

future processing costs will be excessive. Only by being flexible in its choice of a computer system can EODMS hope to offer products at acceptably low prices.

Follow-On imagery at 30 m resolution appears to be more useful than current 80 m resolution imagery.* Thus, we cost the system assuming 30 m Follow-On imagery and the CDC 7600 as the central processor. The total production costs associated with processing Follow-On Imagery on the CDC 7600 for production of the fundamental products are presented in Section 4.4.1.5.

4.4.1.2.3 Estimating EODMS I/O Equipment Requirements

In this section we estimate the number of input/output (I/O) devices required by the EODMS computer system for efficient priority product production. For the most part, the cost of the regular I/O devices, such as disc and tape units, is included in our estimates of the cost per CPU minute (see Section 4.3). Some of the required I/O devices, such as the number of hard copy plotters and high-resolution graphic terminals required especially for priority product production, however, cannot be considered standard equipment. We therefore consider their cost in addition to the EODMS annual production costs alread determined.

To output the priority products derived from digital data in a photoreproducible form, EODMS must have a number of hard-copy graphic plotters. Currently available plotters can be classified into one of two types: dot, or rasterized, plotters and pen plotters. The chief advantage of a dot plotter is its plotting speed; once rasterization has been accomplished, a dot plotter is typically four times as fast as a comparable pen plotter. The pen plotter, on the other hand, does not require an image to be rasterized. In addition, it achieves higher quality plots. After comparing the two types of plotting techniques, we believe that the slower pen plotters are required

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*See Section 2.5 and Chapter 3

to produce products of photoreproducible quality.

To estimate the number of pen plotters required for the EODMS we first estimate the annual number of map or overlay products EODMS produces. These products are listed in Table 3.4 of Chapter 3. Knowing the scale and extent of coverage for each product, we can determine the total number of initial copies of each priority product required annually. To produce the EODMS satellite-derived priority products at their expected update frequency requires that 2,490 maps/overlays be produced annually. Assuming that six overlays on the average are made per product, EODMS must produce 14,940 plots per year.

Because plotters are mechanical and more breakdown-prone than electronic devices, we assume 100 plotting hours are achieved per month. Further assuming an average sheet requires eight minutes to plot (4-10), a single plotter can produce 18,000 plots per year. Thus the EODMS requires two pen plotters for map and overlay product production.

The cost of a suitable pen plotter is $125,000.(4-10) A minicomputer to drive it and software to interface it with the main computer might bring the cost to $300,000, or perhaps $500,000 for two if some software is shared.

Similarly, the system needs a number of high-resolution video terminals to allow data analysts to supervise image processing interactively and to compile maps. We estimate the number needed by estimating the number of analyst-hours expended annually and by making a correspondence between analyst-hours and terminal hours. From Table 4-8, fifty-four equivalent images must be processed annually to produce the priority products. We assume three analyst-weeks to process each image. In addition, 2490 map products are compiled per year. We assume that most of this data compilation is done automatically, with only one analyst-day of human intervention needed per product. Thus, the center expends 660 analyst-weeks (or about 14 analyst-years) per

year. Assuming further that the center operates 50 weeks per year and that analysts spend one-third of their time at terminals, the system must support five terminals. One example of a suitable terminal is the high-resolution video display termianl currently used by LARS, with an estimated cost of $50,000 per terminal.(4-11) The total cost of the five terminals needed is thus about $250,000.

The processing center needs line printers to provide both hard-copy printer maps and to provide hard-copy output for EODMS data base activities. We have been unable to quantify EODMS users' needs for line printer output, but as an alternative, we contacted computer manufacturers to determine the number of line printers a system the size of the EODMS processing center typically requires. A typical CDC 7600 computer system supports three high-speed line printers; the cost of a suitable 200 line-per-minute printer is $102,000 (4-12), or about $300,000 for three printers.

Similarly, we specify the number and type of bulk storage devices the system uses. The best way to determine these needs would be to answer the following questions: How much main storage do the system's processing and data base management programs require? What is the optimum tradeoff between adding more main storage and adding more disc storage? How much data should be kept on-line (on discs); how much will be kept on tape, and how often is each type accessed?

We do not answer these questions fully in this preliminary analysis, although Section 4.4.1.5 discusses them. Instead, to estimate the bulk memory requirements and costs, we contacted computer manufacturers to determine these requirements for comparable systems. A typical CDC 7600 system requires six tape drives and thirty double-density disc drives; suitable tape drives cost $28,000 each, while suitable disc drives cost $40,000 each (4-12). In

addition, controllers are required to interface the bulk memory devices to the system processor. A suitable tape controller costs $80,000 and will control up to eight tape drives; a suitable disc controller costs $99,000 and controls up to eight disc units.(4-12) The total cost for the system's bulk memory devices and associated controllers is $1,840,000.

Totalling all costs derived in this section, we find that the estimated cost for the system's I/O and bulk memory devices is $2,830,000. Assuming a system lifetime of twenty years, equipment lifetime of five years, and a discount rate of 10%, the annual cost of this equipment is $763,000. Adding the yearly CDC 7600 CPU lease charge of $532,000.(4-4), the total annual cost for computer equipment at the center is about $1,300,000.

4.4.1.3 Aerial Photography and Ground Survey Missions: Description and Cost Estimates

In this section we outline and examine the cost of the aircraft and ground verification surveys that the satellite-based production center must fly. These missions support the satellite-derived products or supply basic data for the aircraft-based products.

4.4.1.3.1 Aircraft Missions

The "fundamental" product idea is again useful in identifying overlaps in aircraft-derived input data requirements. Aircraft sampling missions flown to support the four satellite-derived "fundamental" products should supply all the aircraft data needed to produce the eighteen priority products based on interpreted satellite data. This follows from the fact that these four products cover at least the same area and are updated at least as frequently as the other fourteen.

In a similar manner, we can define five additional aircraft-based "fundamental" products. These products contain all information derivable from aircraft data and useful in producing the seven priority products which do not use satellite data. These five aircraft-based fundamental products are:

1) Topographic Maps

2) Orthophotoquads

3) Flood-prone Area Maps

4) Earthen Dam Condition Maps

5) Sinkhole Location Maps

A check of the priority product tables in Chapter 3 shows that these five products dominate the remaining two in coverage and update requirements. Table 4-9 describes the aircraft missions needed to produce the nine fundamental products and therefore the remaining priority products.

We assume that each of these missions is flown separately; that is, that no overlaps beyond those identified by the fundamental product idea are possible among these missions. Compared to satellite missions, aircraft missions must be scheduled, are more prone to the vagaries of the weather, and take considerably longer to cover a target adequately (especially a scattered target, e.g. earthen dams). In addition, the seasonal requirements and the type of photography desired, (i.e. B & W, B & W stereo, CIR, B & W IR)* are different for many priority products. Thus, to be conservative in our cost estimates, we assume that the eleven missions shown in Table 4-9 are the minimum number needed to produce the priority products. While it is true that one plane could carry several sensors and, in isolated instances, serve more than one of these missions, we ignore this possibility. Scheduling problems make these instances nearly impossible to identify in this preliminary analysis. Thus we opt for defining a maximum or "worst case" aircraft data acquisition load for the center.**

*See key, Table 4-9.

**In comparing satellite and aircraft-based centers, this assumption might make satellite centers look slightly worse. However, the comparison is such that this cannot matter, as we shall see in Section 4.4.3.

Table 4-9: Aerial Photography Requirements in Support of the Priority Products

Product	Platform	Type of Imagery	Annual Coverage	Annual Coverage (km^2)
Level II Land Use A Level II Land Use B	H/A M/A	B and W, CIR B and W, CIR	2% Total Area 10% Total Area	16700 1670
Vegetative Cover Map	H/A M/A	CIR CIR	1% Total Area 2% Non-Urban and Non Forested	8350 10855
Forest Inventory (Timber Volume Est)	M/A	CIR, B and W	2% Forested	5177
Recreation Maps	M/A	CIR, B and W	0.5% Total Area	4175
Lake Trophic Status and Water Impdmt Vol.	M/A	CIR, B and W IR	0.05% Total Area	420
Topographic Map	M/A	B and W Stereo	5% Total Area	41750
Orthophotoquad and Geologic Maps	H/A	B and W	20% Total Area	16700
Flood Prone Areas	L/A	B and W Stereo	4% Total Area	33400
Earthen Dams	L/A	B and W, CIR	0.01% Total Area	85
Construction Mtl's Availability	M/A	B and W, CIR	0.2% Total Area	1670

Key: H/A = high altitude (40,000 ft.)
M/A = medium altitude (10,000 ft.)
L/A = low altitude (4,000 ft.)
CIR = color infrared
B and W = black and white

We estimate photography acquisition costs for these eleven missions from USGS figures for privately contracted photography expenses (4-13):

Imagery Type *	Coverage Area/frame	Cost/ Linear Mile
H/A	80 km^2	$30.00
M/A	2.78 km^2	$ 7.50
L/A	1.3 km^2	$10.00

To estimate the number of linear miles required annually for a given mission, we employ the following equation in the mission's annual coverage area and the area covered by a single frame:

$$\#\text{linear miles} = \sqrt{\text{Area}(km^2)} \times \sqrt{\frac{\text{Area}}{\text{Area/frame}}} \times 0.6\ {mi}/_{km} \times \varepsilon \qquad (4\text{-}1)$$

$$\text{where } \varepsilon = \begin{array}{l} 1.25 \text{ for H/A} \\ 2.00 \text{ for M/A} \\ 1.25 \text{ for L/A} \end{array}$$

Without the multiplier, Equation (4-1) gives the number of miles that would have to be flown if the area to be covered were perfectly rectangular. The factor ε recognizes that in practice, these areas are not rectangular. Values for ε are estimates by EODMS staff.

Table 4-10 displays the resulting annual acquisition costs estimates. The total annual cost for all required photocoverage is about $1.08 Million.

In addition to acquisition costs, we must estimate processing (photointerpretation and cartography) expenses associated with each aircraft mission. In addition, some photointerpretation is done on satellite imagery both in support of the machine processing system and to produce geologic maps. We use the following figures in constructing estimates of photointerpretation and cartography times:

*See Key, Table 4-9

Table 4-10: Costs of Aerial Photography Acquisition in Support of the Priority Products

Product	Platform *	Annual Coverage (km^2)	Annual Cost (dollars)
Level II Land Use A	H/A	16700	42,700
Level II Land Use B	M/A	1670	9,200
Vegetative Cover Map	H/A M/A	8350 10855	21,300 59,600
Forest Inventory (Timber Volume Est.)	M/A	5177	28,400
Recreation Map	M/A	4175	22,900
Lake Trophic Status and Water Impoundment Vol.	M/A	420	2,300
Topographic Map	M/A	41750	229,100
Orthophotoquad	H/A	167000	427,100
Flood Prone Area Map	L/A	33400	223,400
Earthen Dams	L/A	85	600
Construction Mtl's Availability	M/A	1670	9,200
		TOTAL	$1,080,000

* See Key, Table 4-9

Imagery Type	Interpretation Rate	Multiplication Rate for Mosaicing and Other Preparation	Cartography Hours per Photo-interpretation Hour
Satellite	40 hrs/10^4km^2	1	0
H/A*	150 hrs/10^4km^2	2	1/5
M/A*	300 hrs/10^4km^2	5	1/5
L/A*	600 hrs/10^4km^2	7.5	1/5

The satellite imagery photointerpretation rate is from (4-14). The aircraft rates are approximately twice as fast as those reported in (4-14) for Level-II Land Use. The rates are doubled because the majority of products to be interpreted do not require the detail of Level II Land Use.

We estimate the number of cartographers to be one-fifth the number of photointerpreters. The majority of cartographic work is related to detailing political and cultural features and marginalia on map products. No accurate estimate of time involved in these activities was available, so our estimate is somewhat arbitrary. In addition to image classification, further photointerpretation is required in the production of flood prone area maps. These maps require intensive efforts to define contour intervals.** We assume a contouring rate of 2 hrs/km^2 for this product.

Table 4-11 presents our estimates of required person-hours of photo-

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* See Key, Table 4-9.

**Topographic mapping also requires contouring, but we have assumed that the reported automated system (4-15) for topographic map production is available and thus have not charged for photointerpretation. However, flood prone area maps require contour intervals of 1 ft to 5 ft as opposed to the typical 10 ft intervals on conventional topographic maps. To our knowledge, no automated system is capable of meeting this requirement. Thus, manual methods must be employed.

Table 4-11: Personnel Times and Cost: Photointerpreters and Cartographers

Data Type	Interpretation Area (km^2)	Interpretation Rate/10^4 km^2	Mosaicing and Preparation Factor	Interpretation Time (MA-Yrs)	Cartography	Annual Expenses*	
						PI	Cartography
Satellite Imagery 46 equivalent images	185,000	40 hrs	1	4	0.	$ 160,000	0
High Altitude A/C Imagery	192,000	150 hrs	2	3	.6	$ 120,000	$ 14,500
Medium Altitude A/C Imagery	64,700	300 hrs	5	5	1.0	$ 200,000	$ 24,000
Low Altitude A/C Imagery	33,500	600 hrs	7.5	8	1.6	$ 320,000	$ 38,500
Contouring	33,400	2 hr/km^2	0	33	6.6	$1,320,000	$158,000
Absenteeism				2	.2	80,000	
TOTAL				55	10	$2,200,000	$235,000

*Annual Expenses are based on the hourly charge rates for USGS personnel reported by (4-14). These are $20/hr for photointerpretors and $12/hr for cartographers. These become $40,000 and $24,000 per annum respectively.

interpretation and cartography derived using the above figures. It also presents estimated salary costs, using a rate of $20/hour for photointerpreters and $12/hour for cartographers (these charges include overhead) (4-14).

As can be seen in the table, the facility needs a total of 55 photointerpreters (including an allowance of two for absenteeism) and five cartographers. Of the photointerpreters, 33 are devoted full time to flood prone area map production.*

4.4.1.3.2 Ground Truth Missions

In addition to these aircraft missions, certain specialized products such as soil maps require intensive ground verification and sampling. A regional center theoretically could take advantage of overlapping needs to schedule ground verification and sampling surveys effectively, and we assume that it does so. We estimate ground truth requirements by referencing Appendix B.

The single largest ground truth effort is associated with soils maps. As detailed in Appendix B, a soils study in Missouri based on LANDSAT data required four man-years to map 800 km^2. We assume that LANDSAT Follow-On imagery significantly impacts soils map production so that only one man-year of ground truth is required for 800 km^2.** This implies an effort of 52 person-years per year to map the approximately 42,000 km^2 per year on a 20 yr. update interval for the five states.

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* Given this fact, institutions implementing a center like the one described here might want to reduce the amount of Flood-prone Area Mapping (e.g., by reducing update frequency to twenty years from five). This might require a legislative change.

**This assumption is suggested by the fact that Follow-On's Thematic Mapper will be tuned to vegetation, enhancing discrimination needed for soils mapping. If the assumption is not good, and the number of ground truth personnel needed becomes 208 instead of 52, total system costs could increase by 15% (see Section 4.4.3).

Vegetative Cover Maps, Land-Use Maps, and other products account for an additional 18 person-years annually. This assumes that the 70 persons involved in ground truthing have sufficient skills to do many product-specific tasks when areas overlap. This substantially reduces the number of ground truth personnel required by consolidating several ground-truth missions into one.

We estimate a salary rate for ground truth surveyors at $20/hr. which makes allowances for expenses and overhead. Table 4-12 summarizes the ground truth missions required and their costs.

4.4.1.4 Production Times and Age of Information on the Priority Products

Because many factors combine to determine how long the system takes to produce a given product, production times are very difficult to estimate. For example, the random nature of cloud cover makes prediction of the time needed to acquire satellite data a statistical problem. Queues at various service points in the system imply unproductive waiting time. Accuracy requirements mean time-consuming verification procedures must occur after the data are processed.

Instead of estimating the total time it takes to produce the product, we believe that it is more meaningful to focus on the age of the basic data (satellite data for satellite-based products; aircraft data otherwise) in the information product when it is first presented to the user. These two times may be very different--at least in the case of satellite-based products. For example, supporting aircraft and ground data for satellite-based products may take months to acquire, but with careful scheduling we can expect acquisition of this data to be nearly complete when it is time to gather satellite data for the product. Thus the basic (satellite) data is relatively new when processing begins.

Table 4-12: Annual Times and Costs:
Ground Truth Surveyors

Product	G-T Time (person-years)	Total Cost*
Level II Land Use A	0.2	$ 8,000
Level II Land Use B	0.3	10,800
Vegetative Cover Map	2.0	80,000
Forest Inventory (T.V.E)	1.7	67,000
Lake Trophic Status	0.3	12,000
Forest Management Map	0.4	16,000
Agricultural Management Map	0.3	10,800
Soils Map	52	2,080,000
Geologic Map	13	540,000
TOTAL	70.2	$2,820,000

*See Appendix B for G-T requirements for seven priority products. G-T requirements for other products are estimated from these, reflecting similar tasks in product preparation. Those products not listed share G-T with those which are listed or involve only photointerpretation or compilation to produce.

Table 4-13 presents estimates of the age of the basic information on the priority products when they reach the user. The table breaks down delays in the system into five categories. The first category, the average age of basic data when processing begins, depends upon the probability of cloud cover (for satellite data), the duration of the acquisition missions (for aircraft data), and seasonal requirements (for both types). Because of cloud cover, it may take about a month to acquire cloud-free satellite data for a given geographic area and season with two, eighteen-day coverage satellites. If data from two seasons are needed, this time increases to about 4 months, making the average data age $\frac{1 + 4}{2}$ or 2.5 months. Aircraft mission duration estimates are based on times observed in actual product production (see Appendix B).

The second category, first digital processing time, should be on the order of a few weeks. Actual time in the computer system is much shorter, of course (on the order of a few hours to one day per image on the CDC 7600, as we showed earlier), but queues at various points and delays caused in interactive processing increase this time. We charge no time for aircraft-based products in this category.

The third category--compilation, photointerpretation, and drafting --is another in which aircraft and satellite-based products differ widely. Digital products can be compiled by computer and plotted automatically in little time, leaving only a queuing delay. An exception to this statement might occur when the satellite-based product contains a significant amount of information based solely on aircraft or ground survey data (e.g., new logging roads on forest management maps). This information would probably be added manually. In addition, with careful scheduling manual photointerpretation can be nearly complete for these products before the satellite

Table 4-13: Information Age Estimates for Priority Products in a Satellite-Based System(Months)

Product	Average Age of Basic Data When Processing Begins	1st Digital Processing	Compilation Interpretation Drafting	Checking	Printing*	Total
Level II Land Use A	1	0.5	0.5	1	1	4
Level II Land Use B	1	0.5	0.5	1	1	4
Vegetative Cover Map	2.5	1	0.5	1	1	6
Timber Volume Estimate	2.5	0.5	0.5	---	1	5
Lake Trophic Status	1	0.5	0.5	---	1	3
Forest Management Map	2.5	0.5	3	2	1	9
Agric. Management Map	2.5	0.5	2	1	1	7
Level I Land Use	1	1.5	0.5	---	1	4
Soils Map	2.5	0.5	0.5	1	1	6
Forest Stand Map	2.5	0.5	0.5	1	1	6
Fire Management Map			on demand			
Water Impoundment Vol.	1	0.5	0.5	---	1	3
Recreation Map	2.5	0.5	0.5	---	1	5
Industrial Map	1	0.5	0.5	1	1	4
Structural Geology	15	---	3	1	1	20
Surficial Materials	16	0.5	---	1	1	19
Flood Innundation			on demand			
Construction Materials Availability	4	0.5	---	---	1	7
Topographic Map	15	---	12	2	1	30
Slope Map	---	---	2	1	1	4
Orthophotoquads	6	---	1	---	1	8
Geologic Maps	16	---	3	1	1	21
Flood Prone Areas	15	---	12	2	1	30
Earthen Dam	3	---	1	---	1	5
Drainage Basin	7	0.5	2	---	1	11
Sinkhold Location			on demand			
Average Age						10

*Printing times were assumed to be 1 month as explained in the text. Presumably rough copies of the products would be available to some users before final printing.

data is gathered for these products. On the other hand, for aircraft-based products, these operations must be carried out after the basic data (or at least a significant portion of it) is gathered.

The final two categories are similar for either type of product. Checking entails verifying a rough draft of the product in the field. We have no way of making printing time estimates; present topographic map printing procedures take years, but most of this time is queuing delay at the Government Printing Office.(4-16) An efficient printing system should be designed to minimize print time for these products, whose age is more critical than that of topographic maps. A one-month turn-around time should be adequate. Moreover, we suppose that an on-demand user could get a rough copy (perhaps with an electrostatic plotter) within a week of a request for information in the printing process.

4.4.1.5 Summary of Annual Production Costs* for the Satellite-Based Center

The annual system production costs are summarized in Table 4-14. Costs associated with digital interpretation assume Follow-On imagery processed on the CDC 7600 as described in Section 4.4.1.2. Costs associated with photointerpretation, cartography and ground-truth and related processing are developed in Section 4.4.1.3.

The costs presented in Table 4-14 reflect some costs for capital investment and overhead. Only those capital and overhead charges directly associated with processing are included, however. Administrative overhead and capital charges for buildings and other equipment peripheral to the production process are not included in this table; they appear in the overall system cost estimates of Table 4-19**. We delay presenting this table until Section

*That is, costs directly associated with production and excluding overhead charges for facilities, administration, and support personnel.

**For example, we charge only for the 40% share of the computer facilities used in processing here, while in Table 4-19, total computer costs (see Section 4.4.1.2.3) are charged.

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Table 4-14: Annual Production Cost Estimates for a Satellite-Based Center

Product	Satellite Data	Satellite Data Processing	Aerial Data (Delivered)	Aerial Data Processing (Interpretation)	Cartography	Ground Truth and Related Processing	Printing	Total
Level II Land Use A	7,200	39,300	42,700	10,000	2,000	8,000	15,000	124,200
Level II Land Use B			9,200	2,000	500	10,800	26,000	48,500
Vegetative Cover Map	12,000	585,000	80,900	37,600	2,000	81,000	74,000	932,500
Timber Volume Estimate	--	3,000	28,400	15,500	3,000	67,000	--	116,900
Lake Trophic	--	1,000	--	--	500	12,000	74,000	87,500
Forest Management Map	--	--	--	--	2,000	16,000	39,000	57,000
Agric. Management Map	--	--	--	--	500	10,800	519,000	530,300
Level I Land Use	--	--	--	--	2,000	--	15,000	17,000
Soils Map	--	--	--	--	1,500	2,080,000	130,000	2,211,500
Forest Stand Map	--	--	--	--	1,500	--	161,000	162,500
Fire Management Map			On Demand			On Demand		
Water Impoundment Vol.	--	--	2,300	1,300	500	--	44,000	48,100
Recreation	--	--	22,900	12,500	2,500	--	6,000	43,900
Industrial Map	--	--	--	--	500	--	195,000	195,500
Structural Geology	--	--	--	--	8,000	--	10,000	18,000
Surficial Materials	--	--	--	--	1,500	--	130,000	131,500
Flood Innundation Area			On Demand			On Demand		
Construction Materials Availability	--	--	9,200	5,000	1,000	--	130,000	145,200
Topographic Maps	--	--	229,100	125,300	25,000	970,000	--	1,349,400
Slope Maps	--	--	--	--	--	309,000	202,000	511,000
Orthophotoquads	--	--	427,100	100,200	2,000	--	42,000	511,300
Geologic Maps	--	--	--	--	2,500	540,000	130,000	672,500
Flood Prone Area	--	--	223,400	300,600	60,000	1,400,000	104,000	2,088,000
Earthen Dam	--	--	600	800	500	2,000	26,000	29,900
Drainage Basin	--	--	--	--	1,500	--	44,000	45,500
Sinkhole location			On Demand			On Demand		
Total	19,200	628,300	1,075,800	610,800	121,000	5,507,000	2,116,000	10,140,000

4.4.3 so that it can be compared with a similar table for the aircraft-based center described in Section 4.4.2.

We note that printing costs are current charges for topographic map production at the appropriate scales.(4-16) These costs are for production of 5000 copies of each product, a fairly arbitrary figure. The overall production costs for the satellite-based center are $10.1 million annually*.

4.4.1.6 Data Management at the Regional Center

4.4.1.6.1 Introduction

This section very briefly considers data management within the proposed satellite-based regional processing center.** We identify major data processing tasks and their interrelations and outline the physical and logical implementation of the center's data base management system. The reader interested chiefly in the cost comparison of the aircraft and satellite-based centers may skip to Section 4.4.2.

Data input at the regional center is digitized satellite imagery, aerial photography, and ground truth reports, while outputs are priority products digitized on tapes or produced in the form of maps, overlays, and tables. In between input and output, the satellite data must pass through the steps of radiometric and geometric correction, reformatting and registration, interpretation, checking, and reformatting for output. The task of data base management is to access the data and present it in appropriate form to application programs and human analysts. Data base management system (dbms) design includes the specification of both the logical data structures and physical storage devices necessary to carry out these functions.

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*Note that the satellite data cost at $800./image is only 0.2% of the total system production costs.

**A much more detailed analysis will appear in a forthcoming report from the EODMS staff.(4-17)

This dbms design postulates that previous generations of the finished products are on file. The CDC 7600 system proposed in Section 4.4.1.2.3 supports the dbms. We emphasize satellite data handling; computer support for aircraft-based products is discussed only in passing.

We use the following method for dbms design: (1) examine the logical data structures required by each application program; (2) combine these data structures economically into a global logical data organization which expresses all data interconnections required by the users, and (3) assign physical storage to all the data. The physical organization must take into account both the available hardware and the expected pattern and frequency of utilization of data by the various programs.

4.4.1.6.2 Processing Steps and Files

Figure 4-2 shows the major processing steps likely to be used in producing the satellite-based priority products. Each step is an application program in the system, and the name of each program appears in a rectangular box in the Figure. The most important files on which these programs operate are also shown in tape or disc symbols; the complete list of files and their relations to these programs are presented later.

The first group of programs in Figure 4-2, preprocessing, uses as input a raw LANDSAT image and outputs a working scene which has been corrected and registered to an underlying geographical grid. Separate steps are provided for parametric correction for variation in the sensor parameters, precise registration with supporting data (i.e. aerial photography), and compensation for scene-related effects (e.g. slope and sun angle).

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*This will be performed, we assume, by an analyst at a CRT. All such interactive steps, with human participation, are underlined in this figure.

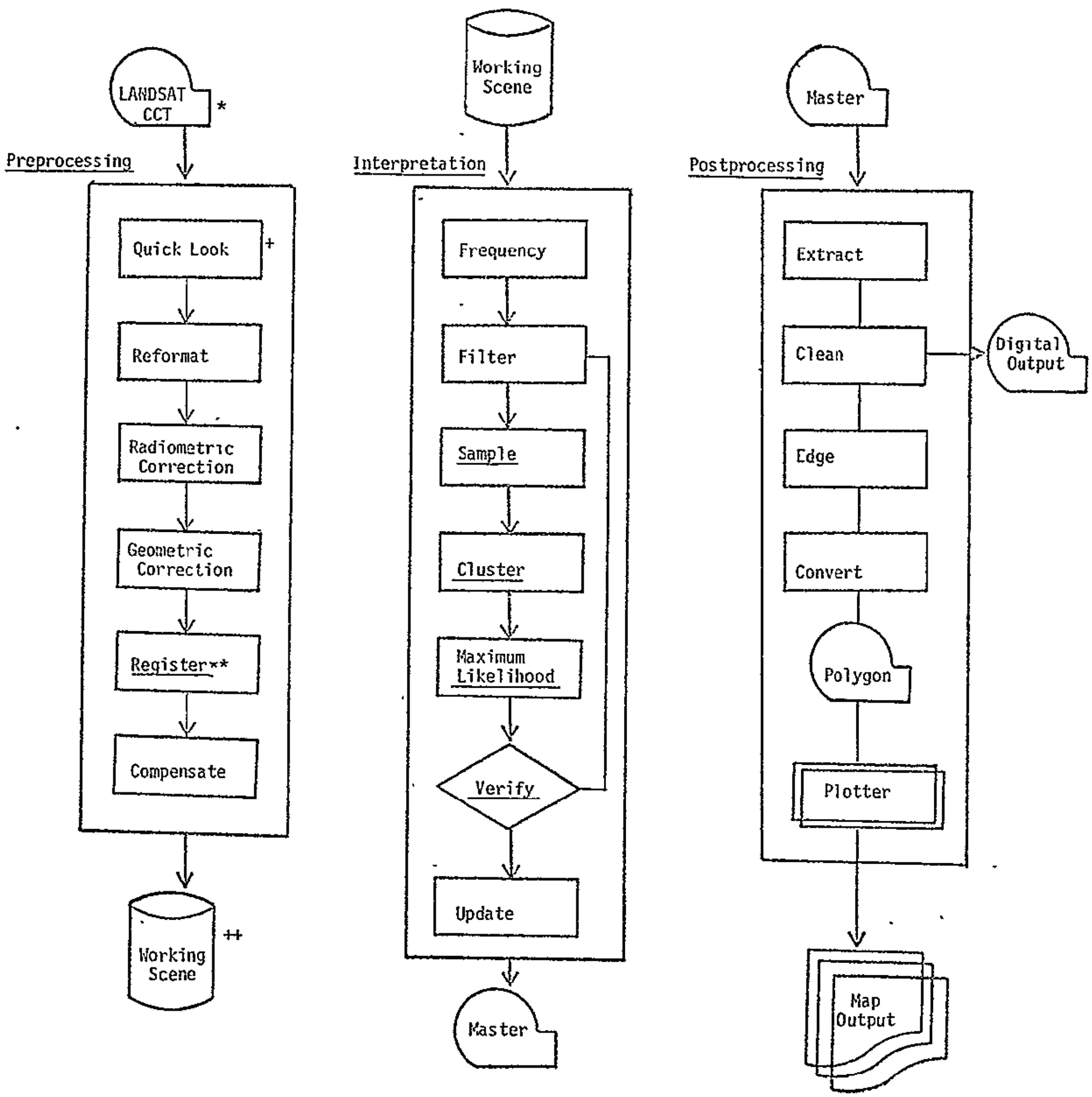

Figure 4-2: Application Programs and Major Files

*Symbol for tape.
**Underlining indicates interactive programs run by an analyst at a CRT.
+Symbol for an application program.
++Symbol for a disc.

The next group of programs is interpretation. This group employs the working image as input, including only those spectral bands necessary for the accurate interpretation of the fundamental product being produced. If appropriate, data reduction is achieved by using a frequency analysis to filter the data to distinguish only the radiance levels that appear useful.* For clustering**, sample areas are chosen by an analyst at a CRT. Maximum likelihood is done pixel-by-pixel either directly or by a lookup table (see Appendix C). After classification has occurred, the result is verified by an analyst at a CRT, using comparison with ground truth, inspection of adjacent pixels or next-most likely class, or comparison with the previous edition of the product. Refinement of the basis classes into subcategories using aircraft or ground truth occurs at this stage. Iteration occurs until classification accuracy is satisfactory, at which time the master file+ is updated with the new classification.

The purpose of the postprocessing group of programs is to output a particular priority product. Categories appearing in the particular product are collected for the area the product covers. The data are then cleaned to eliminate errant pixels,++ yielding the final, digital priority product. This digital product can be output to users on computer tape, or it can be processed further to produce maps or overlays. This further

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*In experiments with a twelve-band sensor at LARS, an average of three of four selected bands of data gave classification accuracy as good as or better than all twelve bands.(4-5)

**Clustering estimates the Gaussian statistics initially used in maximum likelihood classification.

+The master file (explained in more detail later) contains the latest set of information categories corresponding to each location in the region.

++This must be done after extraction, since the procedure will vary depending on which subset of the categories is considered.

processing to prepare the digital product for input to a hardcopy plotter involves edge enhancement to obtain class borders and conversion to code these borders as polygon endpoints.

4.4.1.6.3 Logical Data Base Organization

This section considers the logical organization of data in files - that is, how the data are grouped and addressed. Logical organization is related to physical organization - that is, on what devices the data are stored - in the next section.

Table 4-15 presents major digital files and related applications programs in the production system. The major data structures occurring at the regional centers are large arrays of either image pixels or "cells"* corresponding to geographic locations. These include the satellite images in various stages of correction (whose pixel entries are spectral brightness levels), the products in various stages of correction (whose pixel or cell entries are also spectral brightness levels), and the products in various stages of classification (whose cells contain basis classes). We note two important characteristics of this data. First, it will be processed sequentially pixel-by-pixel or cell-by-cell. Second, it is continuous - there is a pixel or cell for every location.

The logical organization of data in files is influenced both by these two characteristics and by how the data must be organized for the final product. The continuous, sequential nature of the data allows pixels and cells to be addressed conveniently by coordinates. A related issue in organizing data for the final product is georeferencing. In order to use multitemporal inputs and to produce useful map products, it is necessary to register the

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*As explained later, the transition from "pixel" to "cell" occurs as the image data are registered to a geographic location grid.

Table 4-15: Major Digital Files and Related Programs

Type	Name	Unit Of Processed Data	Source Program	Using Program(s)
Imagery (preprocessing)	Raw* Rad-Correct Geo-Correct Registered WORKING-SCENE*	Image Image Image Scene Scene	NASA,** reformat Radiometric Geometric Register Compensate	Radiometric, Display Geometric Register Compensate Filter, Frequency, Sample, Maximum, Lookup
Intermediate Products (interpretation)	Enhanced Semiclassified Fundamental-Prod. Difference Verified-Prod. MASTER CLASS*	Scene Scene Scene Scene Scene Quad	Filter Maximum or Lookup Maximum or Lookup Combine Verify Update	Display, Maximum Display, Maximum, Filter Verify, Combine Verify, Compensate Update Extract, Combine
Auxiliary	Histogram* Gaussian Lookup Table	Scene Scene Class	Frequency Cluster Tabulate	Display, Filter Maximum, Tabulate Lookup
Indices	QUAD INDEX NAMED LOCATION INDEX*	Entry Entry	dbms dbms	dbms, CRT dbms, CRT
Output (Postprocessing)	Extracted CLEANED* Outline Polygon Window	Quad Quad Quad Polygon	Extract, Verify Clean Edge Convert Display, Sample	Clean Page Convert Plotter** Cluster, CRT, Line printer**

*Capitals indicate permanent storage

**Underline indicates external source or users.

data to a common reference system. We assume that geometrically corrected data is georeferenced by a Universal Transverse Mercator (UTM) grid with $(30m)^2$ cell size, corresponding to the anticipated pixel size of the LANDSAT Follow-On. There are about 10^9 such cells in the five state region.

In addition to determining how data is to be georeferenced and accessed, we also must specify how it is grouped at various stages of production. In the stages after georeferencing, the basic unit (or smallest quantity) of information which we must handle for an entire product is determined by the coverage area of the product.* The predominant product scale is 1:24,000, which corresponds to the USGS 7.5' quad. Such quads, containing about 10^5 pixels, are an appropriate basic, logical unit for data storage.

The basic unit of data at the input stages of the system is larger, however, Entire satellite images are registered during preprocessing. Thereafter, processing is done on a subset of the image which we call a "scene," by which we mean the largest area over which the Gaussian signature statistics for classification can be reliably extended. We assume that a scene is equivalent to the set of approximately 350 quads fully contained in a single satellite image.** During interpretation of a scene, the dbms must keep track of which fundamental product is being worked on, what set of quads is included in the scene, and what processing stage in which each quad is. At any time, several scenes may be undergoing processing.

Two other topics to consider in the logical organization of data are:

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*We use the term "basic unit" because the amount of information contained is too large to be called a "record". Column 3 of Table 4-15 lists these basic units.

**The actual quads covered during successive satellite overflights vary; however, we consider quads to be the largest useful permanent basic record units.

1) the contents of files and 2) the distinction between files which are to be stored permanently for the duration of each data product edition and those which are produced by one program for use, once only, by the next program in line. The permanent files* are: raw satellite imagery, which is archived after preprocessing has occurred; the working scene, which contains the registered and fully corrected data; and the master classification file, which contains the current categories of information by cell for every grid cell in the five-state region, topographic and planimetric data, and statistical information for each scene for which classifications are stored. Examples of useful statistical data are frequency histograms and Gaussian statistics, which may be useful in the next update cycle and require very little storage. Furthermore, digital output products may also be stored permanently, or they can be easily reconstructed from the master.

Two final permanent data files contain indices used by the dbms to locate physical records pertaining to quads. The first, a quad index, lists the physical records (e.g., file #4 on tape reel #27) containing past and current data for each quad. The index also lists the records containing each quad's aggregated data, e.g. the most recent update for each fundamental product, or the percentage of area on the product covered by each basic class. The key identifying each quad could be the coordinate pair for its SE corner. The second permanent file for locating information pertaining to quads is a named feature index indicating the location of data for named geographic features such as counties, townships, forests, lakes, etc.

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*Permanent file names are capitalized in Table 4-15.

4.4.1.6.4 Physical Storage

In addition to how data are organized logically into files, the dbms designs must consider how the data are physically stored. Table 4-16 gives rough estimates of storage requirements for digital data at the regional center, illustrates how these estimates were made, and suggests physical storage devices for each major file. The calculations are based on a full year's processing load of fifty-four composite satellite images (see Section 4.4.1.2). Moreover, these calculations take into account the characteristics of the CDC 7600, in particular, its six-bit bytes and its maximum core size, 5.12M bytes.(4-12)

Many of the entires in Table 4-16 are very rough estimates, which we believe are the correct order of magnitude; more accurate estimates require further research. The image size assumes that the LANDSAT Follow-On thematic mapper will have nonlinearities similar to the current multispectral scanner, giving $(\frac{80}{30})^2 \cdot 7.6$ million pixels (Mp) or 54 Mp. The scene size assumes registration to a square grid, and deletion of quads cut by the image boundary. Quad size varies slightly with latitude, but is approximately 97,000 cells.

In addition, the number of bits per item assumes appropriate amounts of information fit into six-bit bytes. For example, we allow three bytes of storage per each fundamental (unverified) product cell. The first byte lists the object class the cell most likely represents; the second byte lists the next most likely class. The third byte lists, to the nearest one-eighth, the probability that the pixel represents each of the two classes, respectively. For the master file we include a fourth byte per cell to contain all current categories displayed on any product for that cell. Some planimetric and topographic data are also assumed to be stored in the master file.

Table 4-16's "numbers of records" entries in parentheses are estimates of the number of temporary products queued up at service points. We

Table 4-16: Physical Storage

Group	File	Data Item	Size* (b)	Segment Type	Size	Record Type	Size*	# Records	Total Storage (Gb)	Medium**
Preprocess	Raw	Pixel	56	---	--	Image	54 Mp ~ 3Gb	54	163.3	T
	Rad-Correct	Pixel	56	---	--	Image	54 Mp ~ 3Gb	(4)+	12.1	D
	Geo-Correct	Pixel	56	---	--	Image	54 Mp ~ 3Gb	(4)	12.1	D
	Registered	Pixel	56	---	--	Scene	35 Mp ~ 2Gb	(4)	7.9	D
	Working-Scene	Cell	56	Quad	10^5	Scene	350 Quads ~ 2Gb	54	105.9	T,D
Interpret (Intermediate Products)	Enhanced	Cell	22	Quad	10^5c	Scene	350 Quads 770 Mb	(4)	3.1	D
	Semiclassified	Cell	12	Quad	10^5c	Scene	350 Quads 420 Mb	(4)	1.7	D
	Fundamental	Cell	18	Quad	10^5c	Scene	350 Quads 630 Mb	(4)	2.5	D
	Difference	Cell	12	Quad	10^5c	Scene	350 Quads 420 Mb	(4)	1.7	D
	Verified	Cell	6	Quad	10^5c	Scene	350 Quads 210 Mb	(4)	0.8	D
	Master	Cell	24	Quad	10^5c	Quad	10^5 p ~ 2.4 Mb	10^4	24.0	T,D
Auxiliary Data	Histogram	Count	18	Band	256	Scene	7 band 32 Kb	54	0.002	T
	Gaussian	Stat.	12	---	--	Scene	44 Stat. 528 b	54	3×10^{-5}	T
	Lookup	Classes	18	---	--	Scene	10^6 18 Mb	(4)	0.1	D
Index	Quad Index					Quad	3 Kb	10^4	0.03	D
	Named Location Index					Feature	3 Kb	$<10^5$	0.3	D
Output	Extracted	Cell	6	Quad	10^5c	Map	1-128Q	≈(600)	0.36	T
	Cleaned	Cell	6	Quad		Map	1-128Q	≈72000	4.3	T
	Outline	Cell	1	Quad		Map	1-128Q	≈(600)	0.06	T
	Polygon	Coords	24	Edge	48b	Map	Variable	(600)	<.03	T
	Windows		6			Window	≤4 Mp 24M	(30)	0.7	D

*Size measures: K = 10^3, M = 10^6, G = 10^9; b = bit, p = pixel, Q = Quad, c = cell

**T: Tape
D: Disc

+See text for explanation of the meaning of parentheses.

uniformly assume four weeks backlog for every temporary file, regardless of whether it is used by a machine or a human analyst. The humans are likely to be the bottleneck, and scheduling must consider this possibility.

More realistic estimates of queue size will consider the number of iterations necessary to produce accurate classification, the throughput rates of experienced analysts in an operational setting, and the distribution of cloud cover. To produce these detailed estimates will require further research.

Table 4-16 displays another important piece of information: For quick retrieval, we assume active temporary files will be stored on disc. This is not essential, since tape storage is also suitable for sequential and continuous data like ours. Ignoring the time needed for tape mounts/dismounts, disc storage is faster. As a comparison, we mention that 844-44 disc drives are approximately three times faster than the 669-4 tape drives, the fastest now available.*

The master class file is too large to keep on-line. Since the dbms records which quads are active, those quads can be transferred from tape to disk as needed. The only file which must be kept on-line is the index, which is quite small, even assuming it has extensive information about each quad.

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*The 669-4 is an eight track, 1600 bpi tape drive which runs 200 ips. A 6250 bpi tape is being introduced.(4-12)

4.4.2 A Design Based on Conventional Processing Techniques

In this section, we estimate costs and timeliness performance for a system to produce our priority products by conventional means (photointerpretation of aircraft data and supporting ground truthing). Some cost estimates are based on published literature or interviews with persons currently involved in production (as in Section 4.2). In other cases, lack of hard data has forced us to associate costs with certain products by noting similarities with other products for which actual data are available. Criteria for this analysis include:

1) Overlaps in data gathering, ground truth and processing are utilized to the fullest for cost savings.

2) No satellite data or automated data processing techniques are used.

3) Only capital and overhead costs directly associated with production costs are included in the estimates in this section. Total capital and overhead charges are estimated in Section 4.4.3.

4) Startup costs are ignored.

4.4.2.1 Estimation Procedure

Production costs are identified in two ways. The first is the aggregated (or total) cost for each product, while the second is production cost broken down by function. As discussed in Section 4.2, the cost data we have are totals, not always broken down by function, so the cost breakdown figures are more speculative than are the totals.

We assign annual production costs to the twenty-four regularly produced priority products. Two products are not costed because they are produced upon demand, so annual product expenses are difficult to estimate. Expenses involved in acquiring the third product not costed, the imagery and digital data sets used in generating the other products, are accounted for in the costs of the other products. The twenty-four products costed are the same

twenty-four analyzed in the previous section on the satellite-based system, so cost comparisons are consistent.

We base this section's cost estimates on the detailed cost breakdowns known for nine of the twenty-four products costed (see Section 4.2 and Appendix B). For these products the per km^2 costs of a given production step are multiplied by the amount of coverage area required per year for the five-state region. We appraise the production methods of the remaining fifteen products and associated costs by comparison with the first nine. We add any additional costs for processing, analysis, ground truth or data collection for these products.

The following subsections analyze the component costs of production (aircraft and ground data gathering, photointerpretation, map compilation, printing, etc.) and present component and total costs. In addition, as in Section 4.4.1.4, we estimate the age of the information on priority products produced by this center.

4.4.2.2 Aircraft Data Required and Acquisition Costs

To implement the aircraft-based production system, much aircraft data would be generated and used each year; we assume in evaluating this system that no satellite data or digital processing is used. In this section, we estimate costs for the yearly aircraft coverage of the five states necessary to produce the product menu. Our estimates are based upon USGS figures (4-13) for costs of aerial photography and on the area of coverage required for each product. The aircraft data acquisition costs are estimated using the method of Section 4.4.1.3.1.

To eliminate redundant costs, we combine the imagery requirements of those products which we believe can share the same imagery inputs. Therefore, in our cost listing, several products may be associated with a single cost

estimate. Table 4-17 lists the aircraft missions required and estimates of their cost. Products which share aircraft data are grouped in the table.

4.4.2.3 Ground Truth Requirements and Associated Costs

Because we lack specific data, we infer ground truth from the overall personnel time requirements in Section 4.2 and Appendix B. In addition, we are again forced to estimate ground truth requirements for the fifteen products not analyzed in detail in Section 4.2 by noting similarity to the nine products on which we have detailed information. For example, we assume that ground truth requirements for forest stand maps are comparable with that for timber volume estimation. Finally, where more than one product may be served by the same ground truth mission, we assume that they share the data, and we reduce costs accordingly. Table 4-18 summarizes ground truth requirements and associated costs, based on an assumed salary of $12,500 per year for ground surveyors. Overhead for field expenses, fringes, etc. of $7,500 per year is added to this figure.

4.4.2.4 Total Production Costs

We estimate total production charges as described in Section 4.4.2.1. To the data gathering costs calculated above, we add charges for photointerpretation, map compilation, field expenses, printing, etc. Table 4-19 lists the total production expenditures for the twenty-four products. It also breaks down compilation, analysis, data gathering, and printing charges.

4.4.2.5 Production Times and Age of Information on the Priority Products

The time factors in the production of the priority products menu are difficult to assess, because most of the products are not now being systematically produced for the five-state region. Indeed, only two (topographic and soil maps) of the twenty-seven products have a regular production schedule in the region. We attempt to determine production times for each

Table 4-17: Annual Aircraft Coverage and Associated Costs for An Operational System

Product	Required Annual Coverage/ Platform/Film Type	Costs (in Millions of $)
Soil Maps Vegetative Cover Type Map	95% Coverage/High altitude/ Color IR	1.035
Topographic Maps (line)	5% Coverage/Low Altitude/ Black and White Stereo	.259
Slope Maps and Drainage Basin Map		shared with above
Orthophotoquads	20% of area/Low Altitude/ B&W	.440
Level II Land Use Map A	20% Coverage/High Altitude/ Black and White Color IR	.440
Level I Land Use	(same as above)	shared with above
Recreation Map	(same as above)	(same as above)
Forest Management Map	same data from Forest Stand Map	(same as above)
Agricultural Management Map	some data from Vegetative Cover Maps	(same as above)
Level II Land Use Map B	1% Coverage/Low Altitude/stereo	.156
Forest Stand Map	20% of Forested Area/Low altitude/Color IR	.280
Timber Volume Estimate Table	(same as above)	shared with above
Water Impoundment Volume Table	.05% of area/Low altitude/ Color IR	.0138
Lake Trophic Status Map	(same as above)	shared with above
Flood Prone Area Map	4% of area/Low altitude/ Color IR	.240
Earthen Dam Condition Map	.01% of area/Low altitude/ Color IR	.00612
Construction Materials Availability	.2% of area/Low altitude/ Color IR/B&W	.0115
Geologic Maps	5% of area/High altitude/ Color IR/B&W	.440
Structural Geology Map		shared with above
Surficial Materials Map		shared with above
Industrial Map	.01% of area/Low altitude/ B&W and Color IR	.0062
	TOTAL	$3.33 Million

Table 4-18: Annual Ground Truth Requirements and Associated Costs for an Operational Production System

Product	Ground Truth Requirements	Costs (in Millions of $)*
Vegetative Cover Type Map	400 person/year	8.0
Topographic Maps	20 person/year	.40
Slope Maps and Drainage Basin Maps	ground truth as gathered for topographic maps	---
Orthophotoquads	ground truth as for topographic maps	
Level II Land Use Map A	10 person/year	
Level I Land Use Maps	ground truth shared	
Recreation Map	ground truth shared	
Forest Management Map	ground truth shared	0.20
Agricultural Management map	ground truth shared	
Level II Land Use Map B	ground truth shared	
Industrial Map	ground truth shared	
Forest Stand Map	5 person/year	0.10
Timber Volume Estimate Table	ground truth shared	
Water Impoundment Volume Table	2 person/year	0.04
Lake Trophic Status Map	ground truth as for topographic maps	
Flood Prone Areas	16 person/year	0.32
Earthen Dam Condition Map	ground truth from water impoundment volume table	---
Geologic Maps	340 person/year	6.8
Structural Geology Map	ground truth shared	
Construction Materials Availability Map	ground truth shared	
Soil Maps	340 person/years	6.8
Surficial Materials Map	ground truth shared	
TOTAL	1133 person/year	$22.7 Million

*$12.5K/person year salary + 7.5K/person year field expenses.

Table 4-19: Production Cost Estimates for 24* Priority Products
Produced by A Photo Interpretation Based System
(In Millions of $)

Product	Production Costs Data Gathering, Analysis and Compilation (Millions of $)	Printing Costs (5000 copies of each product)	Aircraft Data Acquisition Costs	Ground Truth Costs	Total Production Costs
Timber Volume Estimate Table	1.07	---	.280	from forest stand maps	1.35
Level II Land Use Map A	.052	.015	.50	.024	.134
Level II Land Use Map B	.0725	.026	.156	.008	.263
Soil Map	2.1	.130	.032	6.56	9.14
Level I Land Use Map	.060	.015	---	.011	.086
Vegetative Cover Type Map	4.9	.074	1.35	8.0	15.0
Topographic Map	2.41	.130	.260	.56	3.26
Geologic Map	2.5	.130	.440	6.56	9.63
Slope Map	.092	.130	from topo maps	from topo maps	.202
Drainage Basin Map	.060	.074	from topo maps	from topo maps	.134
Flood Prone Areas	1.5	.103	.240	.32	2.16
Forest Stand Map	.10	.161	.200	.10	.436
Forest Management Map	.037	.033	from Ag. management	from Ag. management	.08
Agricultural Management Map	.60	.519	.440	.40	1.40
Industrial Location Map	.167	.19	.062	.16	.425
Recreation Opportunities Map	.01	.146	from Ag management	from Ag. management	.147
Structural Geology Map	.062	.010	from geo-logic maps	from geo-logic maps	.072
Surficial Materials Map	.051	.130	from soils maps	from soils maps	.181
Construction Materials Availability Map	.051	.130	from geo-logic maps	from geo-logic maps	.181
Earthen Dam Condition	.005	.026	.006	from water impoundment	.037
Lake Trophic Status Maps	.030	.044	.014	.011	.099
Orthophotoquad	.400	.167	.440	from topo maps	1.05
Water Impoundment Volume Tables	.100	.025	from lake trophic status	.40	.165
					Total $ 45.6M

*Three additional priority products; flood inundation maps, fire measurement maps and sinkhole location maps were not assigned annual production costs because of their irregular production schedule.

product data acquisition, processing and analysis times. We eliminate time spent in decision making and administrative delay, because these factors should be minimal in an operational system.

As in our analysis of the satellite-based system, we present estimates of the age of the basic information (the aircraft-derived data) on each product, rather than total production time estimates. Table 4-20 presents these estimates and shows that the average data age on the newly-produced information product is twenty-one months for this system. This compares to ten months for the satellite-based system.

Table 4-20: Data Ages for Priority Products in an Aircraft-Based System

	Data Acquisition Time (Months)		Data Processing and Analysis Time (Months)	Total Data Age (Months)
	Aircraft	Ground Truth		
Vegetative Cover Type	10	10	15	35
Topographic Map	12	24	48	66
Slope Maps	2	12.4	15	29.4
Drainage Basin Maps	2	12.4	2	16.4
Orthophotoquads	2	12.4	4.6	18
Level II Land Use Map A	3	9	6	18
Level I Land Use Map	3	1	6	10
Recreation Map	3	6	8	17
Agricultural Management Map	3	6	4	13
Forest Management Map	3	6	4	13
Level II Land Use Map B	2	2	4	8
Industrial Map	2	2	4	8
Forest Stand Map	2	10	4	16
Timber Volume Estimate Table	2	10	2	14
Water Impoundment Volume Table	1	4	1	6
Lake Trophic Status Map	1	4	1	6
Flood Prone Areas Map	1	4	8	13
Earthen Dam Condition	1	4	8	13
Geologic Maps	2	24	5	31
Structural Geology Map	2	24	5	31
Construction Materials Availability Map	2	8	12	22
Soil Maps	3	24	5	33
Surficial Materials Map	3	24	5	33
Average Data Age				21 months

4.4.3 Cost/Performance Comparisons Between the Satellite-Based and Photo-interpretation-Based Systems

Sections 4.4.1 and 4.4.2 analyze two preliminary system designs for producing the priority products: first, a design employing satellite data where possible; and second, a design using no satellite data but instead relying upon conventional aircraft-acquired photographic imagery. The purpose of this section is to compare the two systems on three criteria--cost, accuracy, and timeliness.

4.4.3.1 Estimated Capital and Operating Costs

The two design sections conclude with estimates of annual production costs for each system. These were $10.1 million (M) and $45.6 M, respectively. We show in this section that total annual costs of the two systems, including all production and overhead charges, are about $13.3 M and $48.3 M, respectively. This difference obtains despite the fact that the two systems are producing the same product menu. Thus, these estimates quantify the cost effectiveness of applying satellite data and computer processing to producing the priority products.*

Although the production cost estimates made earlier contain some capital and administrative costs, they do not make these costs explicit. This section attempts to clarify these costs by reanalyzing the system from the "ground up."

Our primary motivation for doing this reanalysis is that system administration, user services, support personnel, etc., which add to personnel and costs required to operate the center, are not reflected in the costs presented in the earlier sections. Capital equipment costs associated with activities other than data gathering and data processing also do not appear. These

*Of course, the cost estimates could be in error. Changing some key assumptions could influence the "bottom line" estimates by twenty percent or more. However, the assumptions used in system design are as similar as possible for the two cases. Thus we believe that the relative magnitude of the two estimates is correct.

system overhead costs are important. Although time did not permit us to investigate these peripheral costs in great detail, this section provides a rough cost estimate for both the alternative and conventional regional center.

The estimation procedure is an inverse approach to costing the system. We first estimate the number of persons and amount of equipment and facilities needed based on this Chapter's previous work. These figures allow us to estimate other cost factors such as carrying charges, utilities, supplies, and field costs.* Adding these charges to our capital and personnel expenses, we obtain a total system operating cost.

Tables 4-21 and 4-22 present two cost estimates for the satellite-based and conventional centers, respectively. Comparing Table 4.14 with Table 4-21, we see that there is a difference between production and total costs of $3.0 M. Comparing Table 4-19 and 4-22 we note a discrepancy of $2.8M, so total costs for both systems can be expected to be about $3M more than costs directly attributable to product production.

We might modify the total for the satellite-based system by yet another charge, to be completely fair in our comparison. In Table 4-21, we charge only $120,000 per year for LANDSAT imagery (150 images (on CCT's) at $800/image). This does not pay a fair share of satellite manufacture and development costs. Let us assume that private consumers of raw imagery (such as the oil companies) and public consumers (such as our regional center) share satellite costs equally in an operational system. Assume also that there are ten regional centers serving the nation, and that each pay equally for the total public share. Then our regional center is billed for one-twentieth of the yearly satellite costs.

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*An informal visit to USGS's Rolla, Missouri mapping facility also assisted us in quantifying these requirements.

Table 4-21: Costs* Of The Satellite-Based Center

Fixed Costs		Total Costs	Annual Costs
Capital Costs	Buildings: 81000 ft^2 @ $70/$ft^2$	5,670,000	
	Landscape and Parking = 8% Bldg	450,000	
	TOTAL BLDGS	6,120,000	
	Note: Buildings are amortized over 20 years at 10%		719,000
	Equipment**		
	Office and Administrative	184,000	
	Photo Interpretation ($150K, each PI)	8,250,000	
	Cartographic ($100K, each cartographer)	1,000,000	
	Reproduction and Primary Print Equpt.	100,000	
	Photo Processing	100,000	
	Miscellaneous	115,000	
	TOTAL EQUIPMENT	9,749,000	2,520,000
	Note: Equipment is amortized 5 years at 10% for a system lifetime of 20 years		
	TOTAL INITIAL CAPITAL INVESTMENT	15,869,000	
	TOTAL FIXED COSTS		3,238,000

*Assuming a twenty-year system lifetime

**Computer equipment is assumed to be leased and is charged later as an operating expense.

Table 4-21: Costs of the Satellite-based Center (continued)

Operating Expense	Total Costs	Annual Costs
Computing Facilities		
CDC 7600 yearly lease cost		$ 532,000
I/O devices & bulk memory		763,000
Data Acquisition		
(includes LANDSAT and AERIAL IMAGERY)		1,150,000
Personnel		
55 photointerpreters @ $18K/annum.		990,000
10 photointerpreters @ $15K/annum.		150,000
20 computer programmer/analyst @ $18K		360,000
70 ground truth surveyors @ $12.5K		875,000
Note: Total "Base" personnel $2,340,000		
13 administrators @ $25K/annum		325,000
65 support staff @ $10K/annum [30% base]		650,000
16 specialists @ $20K/annum		320,000
Note: Total Personnel 237 Total Salaries $3,635,000		
Fringes (10% salaries)		364,000
Expenses ($25/day each surveyor 5 day week)		438,000
($25/day each specialist 1 day week)		20,000
Note: Total Fringes and Expenses $822,000		
Printing Costs		2,216,000
Utilities and Misc. Supplies (10% Op. Expen.)		917,000
TOTAL OPERATING EXPENSES		10,080,000
TOTAL FIXED COSTS AND OPERATING EXPENSES		$13,318,000

Table 4-22: Costs of The Aircraft-Based Center

Fixed Costs		Total Costs	Annual Costs
Capital Costs	Buildings: 3 stories with 81000 ft^2 per story	12,075,000	
	Landscape and Parking (4% Bldg)	483,000	
	TOTAL BLDGS	12,558,000	
	Note: Bldgs are amortized over 20 years		1,475,000
	Equipment		
	Office and administrative	415,000	
	Photo interpretation	33,750,000	
	Cartographic	2,500,000	
	Reproduction and Primary Print	100,000	
	Photoprocessing	200,000	
	Miscellaneous	215,000	
		37,180,000	6,442,000
	Note: Equipment is amortized over 5 years at 10% discount rate for 20 year system lifetime		
	TOTAL INITIAL CAPITAL INVESTMENT	49,738,000	
	TOTAL FIXED COSTS		7,917,000

Table 4-22 Costs of The Aircraft-Based Center (continued)

Operating Expenses	Total Costs	Annual Costs
Data Acquisition (includes A/C imagery)		4,310,000
Personnel		
226 processing personnel @ $18K		4,050,000
25 processing personnel @ $15K		375,000
1133* ground truth surveyors @ $12.5K		14,163,000
Note: Total 'Base' Personnel $5,625,000		
34 administrators @ $25/K [15% base]		850,000
85 support staff @ $10/K [15% base]		850,000
42 specialists @ $20/K [15% base]		840,000
Note: Total Center Personnel 511 Total Center Salaries $8,165,000		
TOTAL SALARIES 21,128,000		
Fringes (10% Salaries)		2,113,000
Expenses (surveyors and specialists)		6,930,000
TOTAL FRINGES AND EXPENSES 9,093,000		
Printing Costs		2,216,000
Utilities and Misc. Supplies (10% Op. Exp)		3,676,000
TOTAL OPERATING EXPENSES		40,436,000
TOTAL FIXED COSTS AND OPERATING EXPENSES		48,353,000

*See Table 4-18, p.   for explanation of this figure

To obtain an annual satellite cost, assume that two earth observation satellites orbit at a time, that each has an expected lifetime of three years, and that construction, launch, insurance for launch failure, and other costs are (choosing a fairly arbitrary figure) $30 million per satellite. Amortizing the costs of two satellites every three years over a twenty-year system lifetime at ten percent results in a yearly satellite charge of $25 million, or $1.3 million to our regional center. Assume also that each regional center pays a $0.3 million sum yearly (again arbitrarily chosen) to support national data reception facilities. Since all data preprocessing charges are already included in our figures in Table 4-21, the total $1.6 million charge should pay for our center's share of all national satellite data gathering activities.*

Adding the difference between this figure and the $120,000 charge we originally made for satellite data to the totals in Tables 4-14 and 4-21 results in a yearly production cost estimate of $11.6 million, or a total cost of $14.8 million for the satellite based center.

4.4.3.2 System Performance Comparisons: Accuracy and Timeliness

Accuracy projections for the two systems are impossible to make with any certainty. At least two major types of accuracy may be defined: geometric accuracy and accuracy of classification. Neither of these two types enjoys a standard definition. Nevertheless, we attempt here to give some indication of the accuracy performance that we can expect from the two systems.

Geometric accuracy performance is the simpler type to quantify. The USGS promulgates map accuracy standards which we can use. The standards say that on a 1:24000 scale map, 90% of the identifiable points must be within ±12.7m. (±40 ft.) of their true position. At other scales, accuracy standards vary proportionately.

*Even calculated this way, total satellite and computer charges are only 20% of total EODMS costs.

This ± 12.7m. requirement translates into plus or minus four tenths of the proposed LANDSAT Follow-on's 30m. pixel size. Four-tenths of a pixel is the "state of the art" root mean square error capability of geometric correction algorithms applied to LANDSAT data(4-18). Thus we expect that all priority map products produced at scales of 1:24000 or smaller (and all of them are) can be produced with sufficient geometric accuracy by a Follow-On-based system. The aircraft-based system should also be able to achieve this accuracy.

Accuracy of classification is much more difficult to analyze. Definitions of this term vary widely; examples are: (1) the probability that a given number of randomly chosen pixels are correctly classified, and (2) the percentage of ground test points correctly classified.

Indeed, the idea of "correct classification" is ill-defined. Is a "mixed pixel" containing a crop field, a road, and a house correctly classified as "corn and soybeans,""urban and built-up", or "other"?

These difficulties make any comparison speculative. Nevertheless, we note that in Table 4-1, the average classification accuracy quoted for the five satellite-based products is 86%, while the average for these same five products produced by traditional means is 90%. Presumably, we can expect the two systems designed in this chapter to differ by a similar figure.

In addition to accuracy, another relevant system performance measure is timeliness--the age of the basic information on the products received by the user. A comparison of Tables 4-13 and 4-20 shows that, in our estimation, the satellite-based system is far superior in this regard. The average information age for this system is ten months, while it is twenty-one months for the traditional system. Moreover, individual priority products produced using satellite data are "younger" yet; Table 4-13 shows that their average information age is about six months.

We must note again that the ages tabulated in Tables 4-13 and 4-20 assume that the products are produced in a shared system with queueing delays at each service point. Presumably a rough information product can be produced in an emergency by classifying raw satellite data on the computer in a matter of hours with little human supervision. However, this product would not benefit from careful, interactive classification or field verification, and we estimate that these procedures take weeks to do correctly.

4.4.4 Economies of Scale in Information Product Production

In the introduction to this chapter, we argue qualitatively that a regional, multidisciplinary product production facility benefits from economies of scale. These economies are due to centralization along both geographic and disciplinary lines. In this section, we provide quantitative support for this statement.

4.4.4.1 Savings from Multidisciplinary Processing

Multidisciplinary processing* reduces costs per product, compared to producing them independently. We could use either the satellite-based or aircraft-based center to illustrate this fact, since the effect is present in both. However, the reduction in cost due to multidisciplinary processing, as opposed to geographic centralization, is more visible in the aircraft-based center. Processing costs in this center benefit little from regionalization, because traditional photointerpretive methods, carried out by skilled individuals, do not lend themselves to aggregation. On the other hand, overhead costs are likely to decrease with centralization. Therefore, the relevant comparison to make is between processing costs--excluding overhead--for producing priority products independently versus production costs at a multidisciplinary center.

Table 4-23 makes this comparison for products produced by photointerpretation. It compares Table 4-1's processing costs for independently produced products with the multidisciplinary center's charges for the same processing steps, as derived in Section 4.4.2 (see Table 4-19). We see that sharing resources among disciplines reduces cost per unit area an average of twenty-four percent.

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*We use this term to mean the sharing of facilities, equipment, and skills among production processes for all of the priority products in one processing center.

Table 4-23: Processing Cost Reduction for Priority Products Produced in a Shared Facility

Product	A Avg. Cost/km^2 When Produced Independently*	B Avg. Cost/km^2 In An Operational Regional Facility**	% Reduction A to B
Soils Map	$188	$163	7%
Timber Volume Estimate Table	$25.25	$8.10	66%
Level II Land Use Map A	$ 0.88	$0.79	10%
Level II Land Use Map B	$11.93	$7.79	35%
Vegetative Cover Map	$22.62	$15,97	29%
Topographic Map	$77.42	$73.04	6%
Slope Map	$6.02	$4.42	20%
Surface Mined Land Map	$1.81	$1.44	21%
Avg. % Reduction			24%

* See Table 4.1

** See Section 4.4.2.3 and Table 4-17. Note that Table 4-17 includes some overhead charges not included in Table 4-1. These charges are eliminated to make this comparison accurate.

4.4.4.2 Cost Savings Due to Regionalization

Regionalization, or centralization along geographic lines, also brings significant savings. The better illustration of this fact is in the satellite-based center, because both processing and overhead costs decrease here due to centralization. In contrast, the traditional center saves primarily in overhead, as discussed above.

Table 4-21 identifies the major annual costs of the satellite-based center as: capital costs for buildings ($0.3 Million (M) annually) and equipment ($2.1M); lease charges for computer and peripherals ($1.2M); utilities and miscellaneous expenses (0.9M); remote sensing data acquisition ($1.2M); printing costs ($2.1M); and salaries and fringe benefits for computer programmer/analysts ($0.4M), administrators and specialists ($0.7M), photointerpreters and ground truth surveyors ($2.3M), and support staff ($0.7M).

We expect that some of these charges scale linearly with the area covered or served by the center, while others do not. Costs likely to be linearly proportional to coverage area are associated with: equipment for manual photointerpretation, remote sensing data acquisition, printing, and perhaps support staff. Those costs that probably do not scale linearly (they are likely to increase more slowly than linearly with coverage area and are therefore likely candidates for savings due to centralization) are building costs, utilities and miscellaneous expenses, computing facilities, and salaries and fringes for computer personnel, administrators, and specialists-- a total of about $3.5M or 30% of the center's annual budget.

To justify this latter statement, let us assume for example that instead of one regional center, five state centers serve the five states. Each of the five state centers must have room for a computer, data files, a block of offices for administrators and specialists representing each major discipline,

and other space that does not vary significantly with coverage area. Thus building and utilities charges for one state center may be significantly greater than one-fifth of those for a regional center.

Computing facilities at a state center are more expensive per image processed than at a regional center. While the regional facility's processing load justifies using a large, efficient computer (e.g. the CDC 7600) for image processing, this computer would be underutilized at a state facility (about 9% of its time would be employed on image processing). However, processing one-fifth of the region's images on five smaller computers can cost considerably more. For example, if we use Univac 1110's the utilization rate per computer increases to about 44%, but total processing costs increase by more than a factor of four--see Section 4.4.1.3.3).

Time-sharing the larger computer comes to mind as a solution to this problem, but to duplicate the kind of interactive processing available at the regional center, the high-resolution video terminals would have to be tied to the central processor by hundreds of miles of communication lines.* These lines would be costly; based on other work (4-19) we estimate the yearly cost of one such line to be fifty to one hundred thousand dollars. Four such lines could cost nearly as much as the computer itself.

Yet another, perhaps more attractive solution is to set up the larger computer in each state center and use its excess capacity for other chores. Financially this would help the state center, but it might be difficult to accomplish. To use the computer for state government work requires reorganization of the state's computer facilities at the time during which EODMS is being implemented. It seems unlikely that EODMS, which is perhaps outside

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*The bandwidth of these lines could be considerably less than video bandwidth if the terminals contain refresh memories. However, for responsiveness, the bandwidth would still have to be high - perhaps 150 Kbps.

the mainstream of state government, could cause the needed reorganization to occur on a suitable schedule. Renting the excess to the private sector might work if there is sufficient demand and if the computer is accessible. Even if this can be accomplished, there remain the other non-scaling costs to contend with, and computer CPU charges and programmer/analysts together make up less than nine percent of the center's budget.

Considering the additional non-scaling costs, a state center can expect only marginally lower costs than a regional center for computer analysts, administrators, and specialists. Administrators (probably) and specialists (surely) possess special skills needed at either the state or the regional facility. Moreover, more computer personnel are needed to operate five medium-size computers than one large one.

Thus it even seems optimistic to hope that these non-scaling costs at one of the state centers could be only half those at the regional center. If they were, and if all other costs scaled linearly, total costs for the five state facilities would be a factor of $5/2(.3) + .7$ or 1.45 or 45% higher than for the regional center.

Of course, after considering the financial advantages of centralizing from state to region, the obvious question is: why not implement one, national production facility? Perhaps the qualitative arguments against this option are the most telling: a national center loses accessibility to state users and does not benefit from familiarity with local terrain. However, considering costs once again, we see little further financial benefit in centralization to the national level. The reason for this is that not all the "non-scaling" costs continue to benefit from centralization, including costs for computers, computer personnel, and specialists. The regional center already utilizes one of the largest commercially available computers fully. To obtain further economies of scale, a national center would have to employ one of the now-

experimental array processors (e.g. STARAN or ILLIAC IV). These machines are not now being used operationally. Therefore, proven computer technology does not allow us to say that significant further savings in computation costs or in computer personnel are obtainable in a national center.

In addition, the one specialist per discipline at a regional center might be unable to perform similar duties at a national facility. One specialist per discipline per region is a more likely number, so we cannot expect centralization to a national facility to save on specialists' salaries.

Thus the remaining non-scaling costs (buildings, utilities, and administrators) make up less than fifteen percent of the regional center's budget. Therefore if ten regional centers were combined into one national center, and if these costs only doubled while the remaining 85% scaled linearly, the total cost for a national center would be about 88% of that for ten regional centers; if they quintupled, 92.5%. This relatively small saving would have to be traded off against the consequent loss in user accessibility.

CHAPTER 5. POLICY ISSUES IN THE DEVELOPMENT OF AN EARTH OBSERVATION DATA MANAGEMENT SYSTEM

5.1 INTRODUCTION: BASIS AND ASSUMPTIONS

In this chapter, we bring to the foreground a number of significant policy issues regarding the development of operational Earth Observation Data Management Systems. These issues represent questions which must be addressed and answered as, and if, EODMS is to develop. They are difficult questions which touch some of the most difficult issues of our time: privacy, participation, costs and authority of government, and relationships among levels of government.

By and large, the discussion in this chapter is based on our interactions during the EODMS project with suppliers, users, and potential users of remote sensing information. We try to alert decision makers to the existence of these issues and we urge that they be addressed squarely. If we have a bias, it is that planning, decision making, and implementation of an EODMS is most likely to succeed when all affected parties participate openly in the process throughout.

Some assumptions about EODMS are implicit in the discussion to follow. EODMS systems are assumed to be large scale, automated information systems which deliver data products to users at many levels based on satellite, aircraft, and other collection platforms. The products are delivered on an operational basis in formats useful to agencies and individuals in the performance of their tasks. EODMS includes data acquisition, preprocessing, processing, interpretation, and storage, as well as product production and dissemination. It also includes a management structure, provision for user education and training, and the arrangements necessary for adaptation to changing user needs and technological opportunities. While the scope of EODMS services and products remains to be determined, we assume that

coordination with other information services will be an integral part of its operations.

We have grouped our discussion of issues under four major topics: Planning and Implementation; Scope and Coordination; Participation, Management, and Payment; and Outcomes and Impacts. These topics are discussed in the remaining four sections of this chapter; Sections 5.2 to 5.5 respectively.

This chapter, along with the discussion of user needs, priority products, and regional center design in Chapters 3 and 4, provides the basis for synthesis and evaluation of several candidate EODMS systems in Chapter 6. Many of the issues raised in Chapter 5 are discussed in Chapter 6 in the context of particular system alternatives.

5.2 IMPLEMENTATION AND PLANNING

In this section we address three principal issues. First, should an Earth Observation Data Management System be implemented at all? Second, what planning mechanism might be instituted in order to plan for the implementation of EODMS? Third, what strategies might be adopted for the implementation of a system, if the decision to go ahead is made? In subsequent sections we will discuss what exactly is to be planned for and what might be implemented. Thus, to some extent the separate consideration of planning and implementation as issues is somewhat artificial, but it is helpful to the exposition.

5.2.1 Should EODMS Be Developed?

The EODMS Project has taken no position on the question of whether an EODMS should be implemented, for both intellectual and political reasons. We feel this is a public policy decision to be made within the Federal executive agencies, by the Congress and by the state legislatures. It is not a decision which is properly the province of an academic study group. Furthermore, we believe that further system studies and analyses of the kind discussed at the end of Chapter 6 are necessary before a final decision can be made.

We can however, identify a number of criteria which might be used to decide whether to implement an EODMS. These include factors such as: the demands and needs for information, the capabilities of remote sensing and computerized information technologies, expectations of future needs and opportunities in these areas, and the costs and benefits of the services which an EODMS might provide.

Our user needs survey discussed in Chapter 3 and Appendix A, as well as a number of other surveys performed by other organizations and discussed in Appendix D, has indicated clearly the broad range of needs for Earth

observation information in regional, state, and local agencies. Several of these data needs are based on traditional demands for information which have been met by other techniques. Many others are the result of a general demand and need for improved management of natural resources, the environment, and the use of land.

These general information needs have been made explicit in a number of pieces of legislation and executive orders, many of which originate at the federal level. In Chapter 2.6 of the Preliminary Needs Analysis (5-1), we summarize a number of laws which have been responsible for the growth in information requirements. These laws include the National Environmental Policy Act, the Clean Air Act, the Organic Act, the Resource Recovery Act, and the process of OMB A-95 Review of projects by regional planning agencies. It is important to notice that many of the new demands for data and information at the state and local levels are stimulated by federal programs, which require the states and local governments to collect and analyze a large number of new kinds of information and to incorporate that information into decision making. Some of the federal programs include some funding for data collection and interpretation efforts. Typical of these is Section 208 of the Federal Water Pollution Control Act Amendments of 1972 which mandates basin-wide water planning and provides grants to support this planning including data collection. Several regional agencies have used these funds to explore land use mapping from satellite data. Notable among them is the Ohio-Kentucky-Indiana Regional Council of Governments.(5-2) On the other hand, the states often feel that the data requirements imposed by federal legislation are not accompanied by federal funds to meet their costs. Thus, states face increasing costs of information without coincident resources. Typical of these is the National Environmental Policy Act. Under this act states receive no funding to pay for data needed to make an independent review of

a proposed project's Environmental Impact Statement. They are, therefore, interested in a system such as EODMS which they perceive to be able to meet some of their information needs at lower cost.

Another important criterion for EODMS implementation is the capability of remote-sensing and geographic information systems technologies. Our assessment of the state of the art is that remote sensing from satellites and high-altitude aircraft can contribute significantly but with definite limits toward the provision of the information which states need.(see Chapter 3). On balance, we believe that the existing satellite technologies are somewhat less flexible and capable than their most ardent proponents would claim, but at the same time we anticipate that the future capabilities of these systems will eventually surpass those claims. The major limits on the current technologies are 1) the fact that their spatial resolutions are inadequate to meet many of the decision-making needs of agencies, and 2) the high cost of interpretation of remote sensing information in digital format. It is important to note that decision makers at the state and local level still find map and tabular formats to be the most useful and most desired in their day-to-day work. They are able to relate more readily to photographic imagery than to digital data products, even though both formats may display the same information.

The technology of computerized geographic information systems also poses great promise but has a number of problems. We have reviewed the state of the art of computerized geographic information systems in Appendix F, which is a distillation of a much more thorough treatment of the topic in Sections 2.6 and 2.9 of the Preliminary Needs Analysis Report.(5-1) Some of the current problems with computerized geographic information systems are the high costs of digitizing existing information, unavailability of proven software for conversion among the several georeferencing and geocoding

systems currently in use, incompatability of various computer operating systems, and inadequate attention to user participation and user needs in system planning and implementation.

The decision to implement also depends highly on our expectations of future needs and opportunities in the area of natural resources information and remote sensing technologies. Our assumption is that data needs will continue to increase over the next several years. Demands for management of nautral resources, especially for land management, will grow as population grows and as the supply of good agricultural land becomes limited. If the predictions of less favorable climate over the next several years hold true, then the demands for management of all sorts of natural resources for the production of food may grow quite rapidly. In the area of technology, the current and proposed NASA/civilian remote-sensing technologies do not begin to exhaust the state of the art of resolution and image quality as practiced by intelligence agencies. Thus, we can expect improvements in EODMS input data. Also, developments in computer systems such as parallel-processing and special purpose hard-wired computers offer the promise of greatly reduced costs of information processing, especially if they are tailored to the needs of EODMS.

Yet another criterion for the implementation decision is the cost and benefits of such a system relative to other approaches, and the distribution of those costs and benefits among the various participants (or non-participants) in the system. (The issue of payment for EODMS services is dealt with extensively in Section 5.4.) One approach is to consider the cost-effectiveness of EODMS versus existing systems for providing equivalent data products, as is done in Chapter 4 of this report. A more sophisticated approach is to consider the costs and benefits of data services directly. Two significant problems exist in such an analysis, however. The first is that it is quite difficult to

evaluate the benefits of the availability of information to various parties. Often, information has uses and users which are not known to analysts. Willingness to pay current prices for LANDSAT imagery is surely a poor indicator of the benefits of that information to many persons. It may grossly underestimate the benefits if it replaces expensive ground surveys. Similarly, the unwillingness of others to pay for current products may not so much represent the lack of potential benefit to them as their inability to achieve that benefit due to the high, and uncertain additional costs of extracting useful data from it.

The second difficulty with the direct analysis of costs and benefits is that many of the benefits of having information available today may accrue in the future and thus be even more uncertain than current benefits. Further, if we discount future benefits of information, we may find that a large future benefit is not large enough in current terms to justify the expenditure. Yet, our country's history is replete with situations in which far-sighted public decisions, which might not have been justifiable on cost-benefit terms at the time, have contributed greatly to the strength of our nation. Examples include the land grants to the railroads; the public highway programs; or, indeed, the collection of a wide variety of economic, social, and natural resources statistics, which have proven to have great utility in managing our complex economy today.

It is likely that implementation of EODMS will redistribute the costs and benefits of information collection and use among the levels of government and among the private sector, the public sector, and various interest groups. The question of the exact nature of the EODMS system is intimately connected with the question of who can, or who should pay. Furthermore, as we notice later in this chapter, knowledge is power, and EODMS-based power

will change the relative advantage of various groups in making public choices.

5.2.2 Planning for EODMS

The EODMS study team believes that it would be desirable for various agencies and decision makers to pay more explicit attention to the process of planning for EODMS development. There are two extreme models for planning for EODMS development. The first model is one which is incremental, adaptive and fragmented. Change occurs through a sequence of small actions taken in light of short-range goals and opportunities. The second model is one which is coordinated and anticipatory. Change is directed through consideration of the steps necessary to achieve longer range goals. The emphasis is on creating the necessary opportunities and on participation by many parties in setting the proper goals.

We believe that current EODMS-like planning efforts tend to be of the first type, which is appropriate for the early stages of development of a technology. Most of the decisions appear to be made in the higher levels of NASA and the Department of the Interior with inputs from the Office of Management and Budget. Current planning efforts seem to to be rather seriously limited by the notion that the various federal agencies should perform only those functions they are now performing, and that the major effort in making Earth observation information available to state and local users should be provided by the private sector on a profit-making basis.

The current NASA role appears to be one of flying satellites, promoting user awareness and interest in the technology, and developing future satellite systems.* Current Department of the Interior efforts appear to be

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*NASA has also funded a number of longer range planning studies, including the present study; the Outlook for Space (5-3) report (a NASA in-house effort); and several other studies, some of which are briefly summarized in Appendices D and E.

focused on operation of the EROS data center and on traditional map making, supplemented by high-altitude aircraft input.* Other federal agencies, such as USDA and EPA appear to be aware of and interested in Earth observation data, but also appear to be less involved in long-range program development.** States have been involved in the use of Earth observation data primarily as principal investigators on LANDSAT I and II. As noted above, the states are also developing computerized geographic systems, and some have made significant strides in the use of more traditional remote sensing techniques. It is interesting to note that the National Conference of State Legislatures is currently involved in a NASA-funded program of education and awareness directed toward the members of state legislatures.

The fragmented planning model is probably inadequate for the development of an EODMS of the sort we envision. If EODMS is to work, it will involve many participants with diverse goals and objectives and it will adopt a technological approach which emphasizes overlap and commonality among data needs, inputs, and system services. If all of the actors and actions are to be brought together harmoniously to take advantage of economies of scale and overlaps in data needs, it will be necessary to establish an extensive, participatory planning process for EODMS implmentation.

In addition to broad participation, however, it may be desirable to establish a strong single focus within the Federal government for such planning. The focus group would provide a framework for the broader participation

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*See Appendix G for a discussion of Interior's National Cartographic Information Center.

**USDA, along with NASA and NOAA, is a major participant in the Large Area Crop Inventory Experiment (LACIE) which is felt by many to be a prototype for one kind of future EODMS focused on meeting one critical data need.

we envision. Options for this focus include the new President's Office of Science and Technology Policy; the Council on Environmental Quality; the new Federal Coordinating Council for Science, Engineering, and Technology; a potential new natural resources agency; an interagency remote sensing council; or any one of several existing Federal executive agencies whose charter could be adapted to the purpose such as NASA, NOAA, or DOI. Other possibilities for focus are the Office of Management and Budget, the Congressional Office of Technology Assessment, or one of the Congressional committees concerned with applications of space technology. In our judgment, no group has been willing to seek this focus role. Regardless of the focus chosen, however, we want to reiterate the desirability of participation by suppliers and users from all levels and sectors in the planning process.

5.2.3 Implementation Strategy

If one assumes that a decision is made to go forward with planning and implementation of EODMS, a question arises with regard to the actual strategy adopted for implementation; that is, what should be done, by whom, and in what order? Chapter 6 presents static models of ultimate system development, but pays relatively little attention to the time phasing of the development of those activities.

If we assume that EODMS will be broad in scope with regard to users served and products provided, we still have to ask - where do we begin? EODMS requires a large initial outlay to develop satellite systems and basic data processing capability. Thus, there are significant driving forces for using that capital most effectively by having many products developed almost from the beginning.*

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*In particular, our concept of producing twenty-seven priority products from a basis set of 41 classes suggests that a large number of products might be produced initially. (See Chapter 4).

However, it may be better for EODMS to initially develop a small number of products which can meet widely expressed needs but which can do so with proven technologies. A reasonable schedule might be established for adding additional products over as much as a ten-year time period. Somewhat later, EODMS might add the capability to react to a small number of non-regular data needs of high visibility, such as flood maps or maps of drought conditions.

The regional center concept developed in Chapters 4 and 6 suggests that a nationwide system could initially serve users in one region, such as our five states, as a prototype for full-scale implementation.

5.3 EODMS SCOPE AND COORDINATION

5.3.1 Introduction

In this section we consider four major questions which must be addressed in EODMS design. Three deal with the scope of inputs, services, and products to be provided by EODMS, and the fourth concerns the coordination of EODMS activities with other related activities in state, federal and local governments and in the private sector. The choices of inputs, services and products of EODMS are interrelated, but they can be varied independently to some extent. For example, it is possible to use the same inputs to provide different services or different products to users. Also, it is possible to produce very nearly the same range of products from a different set of inputs to the system. (See Chapter 4). The problems of coordination with other activities are also sensitive to the scope of inputs, services, and products.

5.3.2 Scope of Data Inputs

EODMS could reasonably include among its inputs satellite data, aircraft-based remotely-sensed data, natural resources data based on data collection platforms and ground surveys, socio-economic data, parcel-based data, and personal information. In this section we consider some of the advantages and disadvantages of each.

In its simplest form an EODMS might be based on inputs only from satellites, but satellite information is in general inadequate to deliver the kinds of products which state and local agencies need. Natural resources information obtained from a wider variety of sources including remote sensing from several platforms as well as ground survey and other data collection techniques represents a wider scope of EODMS data inputs. There is considerable merit in considering a system based on natural resources information, since

much of the data required to supplement satellite data in the production of products can also be used to produce other natural resources products.

Socioeconomic data is data on social and economic behavior such as census of population, business activity, location of cultural features, and so on. Many state and local agencies require a combination of socioeconomic and natural resources information to develop useful decision information products. Thus, there is merit in including socioeconomic data in the EODMS data files. The nation already possesses considerable capability for gathering such information through the Bureau of Census, Bureau of Labor Statistics, and so on; and we do not suggest that it is reasonable for EODMS to assume their functions. One might simply include the census information with other natural resources information in the EODMS file; primarily for the purpose of producing such combination products. It may be over-stating the ease with which this may be done to say that the files should be "simply" combined, however. Problems with consistency of format, definitions, and file structures make it very difficult to overlay data from the Census with other sources. (See the thesis by Power (5-4).)

Yet other users require that both natural resources and socio-economic information be available on a parcel basis; that is, identified with legally-defined parcels of land with specified owners or in specified ownership classes. Such information is required whenever regulatory actions are undertaken by agencies. Depending upon the purpose, parcel file systems require great locational accuracy, and it may not make sense to try to overlap parcel-based systems with Earth observation data systems at the current spatial resolution of the latter.

Finally, one might consider including among the scope of data inputs personal information of the sort collected by the Internal Revenue Service,

Social Security Administration, police record systems, and the like. We reject the notion that such data should be included in EODMS. We do so in part for the very pragmatic reason that EODMS should not become embroiled in the considerable controversy which exists with regard to personal data banks.* Secondly, we believe that controversy is well founded and that it will not be in the interests of the people to have a personal data bank in combination with a broad-based natural resources information system. For one thing, the potential for abuse of such personal information would be greatly increased if a wide variety of natural resources managers were to have access to information on individuals.

5.3.3 Scope of Data Services

By the scope of data services we mean the degree of information processing which EODMS provides to users. We envision a continuum from raw data to management information and finally to management decisions. Consider, for example, the case of land use information. At its most primitive, EODMS might provide information to land use managers in the form of imagery or uninterpreted digital tapes. A further service would be provided if this information were interpreted to provide maps or other formats containing land cover information. Still further, such information might be combined with other data having to do with geological formations, ground water movements, socioeconomic activity, and drainage patterns to provide a land suitability map for location of industrial activity. At the extreme, a system might provide an answer to a question such as, "what is the optimum location for a proposed steel mill?"

The current systems for Earth observation data operated by NASA and

*See Section 5.5.1 for a discussion of how the concern for privacy might affeect EODMS development.

USGS provide essentially only the first step; that is, the raw imagery or digital tapes to users.* Our research into the needs and capabilities of state and local agencies suggests strongly that to be effective EODMS needs to deliver information processed all the way through to data products, as discussed in Chapter 3. These products contain "objective" information in the sense that they do not include judgments about suitability, or presentation of information in the form of management decisions. Thus, they are descriptive and not prescriptive of the use of resources.

An important issue in the scope of data services is the dichotomy between the delivery of information on a regular periodic basis and delivery of information to respond to crises or other needs on an irregular basis. We believe that EODMS should include both capabilities, but that initially it should focus on the production of a small number of widely desired regular data products.

Another question in the scope of data services is the format in which products are provided to users. Very few state or local users have or are likely to develop the capability to use information in the digital domain; whether it is raw LANDSAT data, or final processed products, in order to carry out ordinary management tasks. Our analysis shows strongly that maps, and to a lesser extent tabular formats, are most highly desired by agency staff. Maps are used in making decisions, principally through overlays or transfers to base maps. While this can be done in the digital domain, the historical records of such decisions are not. Thus, for comparative purposes it is likely that hardcopy maps and tables will remain important for a very long time.

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*See Appendix G.

5.3.4 Scope of Information Products

Our data needs survey and analysis resulted in the proposal to develop twenty-seven priority data products, as discussed in Chapters 3 and 4. As part of the planning for an EODMS system, it is important that users and potential users continue to be involved in critique and reassessment of the priority products and their characteristics. Furthermore, if EODMS is implemented, it will be quite important to maintain flexibility to respond to changing priorities of the user community.

Priority products should be provided in several formats, with an emphasis on maps and thematic overlays as well as provision for the same information in the digital domain. It will be also important to provide the information at several map scales tailored to pre-existing decision models and procedures in a variety of agencies. Such scales are likely to be chosen in part for the level of detail of information they contain, but also to be compatible with the scale of base maps or with the scale of information ncecessary at various levels of decision making.*

We observed that many different map scales are currently in use in agencies working with natural resources information. In the short run, we think this situation is best approached by making EODMS products available in a number of scales which are compatible with the scales now in use rather than by trying to force adoption of a standard scale.

5.3.5 EODMS Coordination with Other Activities

It will be important for EODMS decision makers to find ways to interface effectively with preexisting systems rather than to seek ways to bend

*Project ASTRO at the City University of New York is designed in part to determine whether it is important to be able to present information at different scales to decision makers at different levels within an organization (5-5).

those systems to meet the EODMS format. Satellite-based natural resources information offers a logical, synoptic framework for coordination of existing geographic information systems. However, this view neglects the difficulty which is likely to arise in attempting to change a large number of existing systems to fit the EODMS framework. In a report completed for the EODMS project, Power reviewed a number of the technical and institutional issues which are likely to arise in connection with EODMS coordination.(5-4) She points out that a number of Federal agencies have developed or are developing geographic information systems using different geocoding or georeferencing systems. Furthermore, many states have implemented various kinds of computerized geographic information systems which use a variety of georeferencing and geocoding systems as well as many different computer languages, operating systems, and so on. (See also Appendix F).

The state and local user community is fragmented in other ways which will require coordination. For example, many of the procedures used for analyzing data or making management decisions are non-digital and _ad hoc_. Also, various laws have requirements for ostensibly the same information, such as "land use" or "critical areas," but the detailed implementation of that legislation by executive agencies has tended to result in non-compatible formats or definitions for collection of such data. Thus, land use information for Section 701 planning under regulations of the Department of Housing and Urban Development is different from land use under Section 208 of the Federal Water Pollution Control Act.

Certain Federal agency coordinating activities already exist for some of the activities of EODMS. For example, the General Services Administration has several relevant areas of responsibility. Among other functions, the GSA Automated Data and Telecommunications Service is the single purchaser of automatic data processing equipment for the Federal government; it

receives all requests for such equipment and determines the capacity required. The National Archives and Records Service archives important government documents and supplies data from these records upon request. The Federal Information Centers (FIC) Program provides clearinghouses for information about the Federal government for all citizens. GSA could have much influence over EODMS development given its experience in collecting, storing, and disseminating information and its role as chief purchasing agency for automatic data processing equipment.

The Office of Management and Budget has a broad responsibility for coordinating all of the activities of federal agencies through the budget process. Of interest to EODMS are those related to administration of the budget, recommendations to the President regarding legislation, coordination and development of Federal and other statistical services, and development of information systems to provide the President with program performance data. (5-6) OMB also develops guidelines and regulations for implementing the Privacy Act. OMB's experience with information systems would render their input and suggestions for an EODMS very significant.

5.4 PARTICIPATION, MANAGEMENT AND PAYMENT

5.4.1 Introduction

In this section we address a number of questions, including who will participate in EODMS; who will operate and manage it; and ultimately, who will pay for its services? Our model of EODMS is based on many users at several levels of government and in the private sector. The benefits to these users of the outputs of EODMS are often diffuse and difficult to quantify. The costs are also widely distributed and difficult to pinpoint. We think, however, that EODMS will be expensive and that its justification will require the aggregation of disparate users. In addition to the large number of government users, we anticipate significant interest on the part of private firms as well as a great deal of interest in participation on the part of various public interest organizations.

5.4.2 Management and Operation

Successful operation of EODMS as defined in Chapters 4 and 6 will require participation by government at all levels in the planning, setting of priorities, operations, control, staffing, and paying for EODMS. Our findings are that state and local governments want to participate in all these levels, but that their technical capabilities and financial base are weak while their needs for information are strong. It is likely that state and local governments would provide the ground truth and other non-remote sensing inputs necessary to the operation of EODMS. At a minimum, they will do so in cooperation with federal agencies. If the states are to cooperate in providing such information, it will be necessary to keep them informed and interested and to give them a stake in the successful operation of EODMS.

In the management of natural resources, many citizens feel that local, state, and federal agencies charged with managing various resources do not

manage those resources appropriately. Often, one or more public interest groups are in conflict with both industry and government over issues such as coal development on federal lands, flood plain protection, range management, and the like.* In order that the interests of citizens groups be adequately represented in EODMS, it is suggested that consideration be given to the establishment of a Citizens Advisory Panel (CAP) with responsibilities for participation in the planning and priority setting of an EODMS system. Membership on CAP should be widely available to interested organizations or to representatives of unorganized interests in some cases.

5.4.3 Public and Private Sector Roles

One of the most difficult issues in EODMS policy is the question of the appropriate roles to be played by the private sector in its operations. The mental models for private sector participation run the gamut from completly public sector operations to completely private sector operations. One can conceive of private-sector data processing companies meeting the needs of private-sector users, or those of public-sector users. Alternatively, one might think of private sector data processors operating under contract to meet the needs of a public sector agency.

On balance, the EODMS study group believes that a model in which the private sector is contracted to perform various well-defined activities for the public sector is the best one. There are a number of reasons for this decision. First, it will be costly and time consuming for the private sector to aggregate the market for remote sensing across many agencies in order to take advantage of the economies of scale and commonality which accrue in meeting the needs of many users simultaneously. Second, we

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*See for example the paper by Shea and subsequent discussion in the Conference Proceedings.(5-7)

believe that some of the functions of EODMS should not pass through the private sector, as a matter of public policy. For example, some functions which are currently carried out in the public sector, such as the preparation of topographic maps, would have to be given to the private sector under EODMS as we conceive it. Futhermore, one could ask whether it is appropriate to remove from public control information about public lands or public resources which are the property of the people as a whole.

Another issue which must be addressed is the question of the point at which a private sector user, or any user, is allowed to access the data stream. Is it appropriate to allow the private sector access to Earth observations information before final products become available to the public? For example, in one model of EODMS, the data services provided will range from a "Quick Look" at low quality digital information, through selling digital tapes of raw data, to provision of final priority information products. Suppose that a delay exists between the time that data are acquired by a satellite and are available in digital form and the time that final information products are produced by a Federal data agency. It might be deemed desirable to sell the raw data tapes to private processors who could make specialized management information products more quickly than could the public sector. On the other hand, by analogy to the current system in use in agricultural crop forecasting, one might want to prohibit private sector access to the raw data until the final output is released publicly. That is to say, an unfair advantage might be given to private sector users who use data acquired at public expense to arrive at early decisions.* Finally, if a private institution desires to acquire such raw data by orbiting its

* Parallel private and public systems exist for the dissemination of weather data and forecasts based on government-acquired raw data. This fact may be a precedent for encouraging such early private sector access.

its own satellite, is there any basis for forbidding it to make decisions based on that information as soon as it is acquired?

5.4.4 Payment for EODMS Products: Pricing

Who should pay how much for EODMS products? In this section we review some of the issues related to paying for information products produced by government. We also examine several pieces of legislation and various precedents related to charging for such data.

5.4.4.1 Options for EODMS Cost Recovery

The costs of EODMS include both capital costs and operating costs. These may be paid by a direct appropriation from general revenues, by recovering costs from users, or by some combination of the two. Both the system costs and the pricing policy may influence the design of an EODMS system. Relatively high system costs may be incurred in a multipurpose system delivering a broad spectrum of products. Table 4-14 indicates that there is a wide variation in production costs among priority products. This suggests that, if large-scale funding should not prove to be available, then more selective product production might be undertaken. However, in this event some of the advantages derived from product overlap would be lost.

For an operational EODMS, several pricing policies are possible. Users might be charged:

1) reproduction and delivery costs only; i.e., marginal costs,
2) full operating costs for each product,
3) operating costs plus a portion of current capital costs,
4) all capital and operating costs, including depreciation of initial system capital.

In a public sector EODMS, there is precedent for selling products at reproduction cost or below full cost recovery. If users are to bear extensive operating and capital costs, a problem arises in assigning such costs for products with multiple users. Would the first user pay the full cost?

Would refunds be computed each time a new user shows up? The original purchaser of a data product may lack the necessary incentive to pay the full cost for it himself. He has a large incentive to wait for someone else to pay the first cost, and vice versa.

One possibility is a pricing policy for the regular priority products in which the cost would be divided among a large number of users, many of whom could not be identified at the time the products are made. For those special products which are made to meet special user needs, those users would pay the marginal costs of producing the additional product. In the framework of producing priority products from a small number of basic information classes discussed in Chapter 4, the production of some specialty products could be much cheaper than if it were based upon fresh interpretation of digital imagery in every case.

5.4.4.2 Some Current Federal Data Pricing Policies

Several federal agencies cooperate with their state counterparts in programs on a cost-sharing basis. There are two types of cost-sharing. In the first type of cost sharing, the state agency performs the work and the federal agency pays part of the program expenses. An example is the Cooperative Forest Management Program (CFM) supervised by the U.S. Forest Service. Under CFM, state farm foresters provide technical advice and services regarding various aspects of forestry. The Forest Service pays for part of the time the farm foresters spend on CFM. The proportions of cost-sharing vary from state to state. Several other programs, including the Agricultural Conservation Program (ACP) run by the Agricultural Stabilization and Conservation Service (ASCS), also cost-share with the state forestry agency.

In the second type of cost sharing, the federal agency performs the task, and the state pays part of the expenses, plus an additional charge

for any special information it requests. The U.S. Geological Survey provides an example. Present plans call for mapping the entire country at 1:24,000. If a state desires a new or revised map ahead of schedule, USGS performs the work and the state must pay 50% of the mapping costs. For a special product, such as a slope map, the state must reimburse the USGS for the full cost.

Title 15 Section 1153 of the U.S. Code states that to the fullest extent feasible, the information collection and dissemination activities of the National Technical Information Service (NTIS) shall be self-sustaining. The fees charged by NTIS reflect this policy. If the information collected by EODMS were disseminated by an agency such as NTIS, Congress might impose a similar policy of requiring such information services to be self sustaining.

The EROS Data Center provides raw imagery at costs that do not reflect all system costs, but are apparently only reproduction costs.

For topographic maps, the USGS charges reproduction and publication costs including platemaking, printing, binding, paper, distribution, postage, obsolescence, spoilage and overhead. Full cost is charged for the initial production of special products, but only reproduction and publication costs are recovered thereafter.

5.4.4.3 Implications of the Freedom of Information Act for Pricing Policy

Under the Freedom of Information Act as amended in 1974 (FOIA), upon a proper request in compliance with agency rules, each federal executive agency must furnish any agency records reasonably described in the request unless the records requested fall within one of nine specific exemptions.

Under the FOIA each agency is requried to draw up and make public a uniform schedule of fees. "Such fees shall be limited to reasonable standard charges for document search and duplication and provide for recovery of only

the direct costs of such search and duplication. Documents shall be furnished without charge or at a reduced charge where the agency determines that waiver of reduction of the fee is in the public interest because furnishing the information can be considered as primarily benefiting the general public."(5-8)

For EODMS the above paragraph appears to limit charges for existing maps acquired pursuant to FOIA to costs incurred in searching for and reproducing the requested document. However, the recovery of search costs for a map that has not yet been compiled may open a pandora's box of fees chargeable to the potential user. May the wages of personnel involved in processing the requested product be recovered? Is computer time involved in processing the product recoverable? What about equity - the statue requires uniform fees - may a user requesting a product which has not yet been processed be charged, say $50,000, while a subsequent user is charged only $2.00 for a reproduction on the grounds that the search costs were higher for the first user? If several users each contribute a portion of the fee for initial processing of a product (e.g. 10 users contribute $5,000 per user for a $50,000 product), may EODMS charge only a $2.00 copying cost to subsequent users? May EODMS promulgate regulations which would distribute processing costs among all potential users without violating the FOIA? Should EODMS documents be furnised without charge or at a reduced charge "because furnishing the information can be considered as primarily benefiting the general public"? Such questions may eventually be answered in the courts.

5.5 OUTCOMES AND IMPACTS OF EODMS IMPLEMENTATION

In this section we choose to speculate about some of the possible outcomes or impacts of successful implementation of an EODMS system of the sort discussed in this report. We do not mean to imply that these outcomes will occur, but rather to suggest that they are additional areas which policy makers need to address.* No special significance is attached to the order in which these items are discussed. However, the issue of privacy is of sufficient importance to be treated separately in Section 5.5.1.

One possible outcome is a large change in the character of NASA. We might envision changes in its charter and in the relative power and authority of the various NASA centers, as well as a shift from emphasis on research to a greater emphasis on service. NASA has already begun to undergo such a transition with its large number of ad hoc programs to transfer space technology to meet user needs.

EODMS may provide the impetus for forming a federal natural resources data agency. Such an agency would absorb many of the programs of existing federal agencies, many of which were initially formed as data collection agencies. In the longer term, a natural resources data agency might provide the logic for a single natural resources management agency in the federal government.

EODMS implementation could lead at all levels to better, cheaper decisions based on better information. As a result we might see pressures for further management of natural resource systems. The availability of data might also serve to sharpen the issues around particular natural resources

*This topic is treated in more detail in Chapter 7 of the Preliminary Needs Analysis Report.(5-1) The reader is also referred to the extensive Preliminary Technology Assessment of Remote Sensing by Zissis, et. al.(5-9)

conflicts and weaken coalitions which form when issues are not so clear.

Implementation of EODMS in the context of computerized geographic information systems will increase the technical sophistication of decision making within government agencies. It might cause more decisions to be made defacto by technical experts rather than by those who are entrusted to do so by the political process. Such a development might lead to further centralization of decision making, and thus reduce the access to decision making which is characteristic of our current system which includes several agencies operating in similar areas. EODMS might also cause the ultimate demise of many current functioning data systems such as that of the USGS, the USDA, EPA and others.

Depending upon the way in which it is designed for adaptation to the future, EODMS could either increase the demand for better technology in the remote sensing and information processing areas or serve to fix technology at the state of the art at the time of its implementation. Such a "fix" could occur because such a large number of systems would be altered to be compatible with the EODMS system.

Another possible outcome might result from the oversell and subsequent failure of EODMS. Such a system will have its weaknesses. By virtue of centralization and the use of overlap and commonality, a failure of EODMS, even for a short time, may be devastating. The current system, characterized by a large number of actors operating in diverse ways, is probably more stable than EODMS will be to external disruption.

Finally, while not within the scope of the EODMS project, we think it important to recognize the potential international conflicts to which EODMS may contribute. The most obvious problem is the ability of the U.S. government or U.S. firms to make assessments of the natural resources or cultural activities of various countries without their knowledge. Even with their knowledge, conflict may arise if such information can be put to use in ways

against which the target country is economically or politically defenseless. The current U.S. policy of open access to data from LANDSAT 1 and 2 in our view is not necessarily in the best interests of those countries for which access is factual but not functional.

5.5.1 Limits to Information Systems - The Concern Over Privacy and Security

Large-scale information systems which serve many users require careful design to balance privacy, access and security. Limitation of access to certain information may be necessary to ensure privacy, yet freedom of information requires that access must not be unnecessarily restricted.

The privacy issue was recently highlighted when a national data bank and a FEDNET system which would pool data from a wide variety of federal agencies was proposed. In an EODMS, if only natural resources agencies are involved and only natural resources information is available, then there may be less concern than if a larger spectrum of agencies, which collect more personal information, are involved.

As an example of present data access policy, USDA has traditionally treated national crop forecasts with great care, releasing the information in a manner that gives no speculator an unfair advantage. System design must be cognizant of such practices. Pricing policy for products and the form of products may also determine the extent to which large organizations can benefit from the data at the expense or exclusion of smaller organizations.

The existence of EODMS might lead to increased concern over personal and economic privacy. Does a land owner have a right to be "let alone" with respect to knowledge about the condition and character of this land? How will land owners respond to the capability of private firms or the government to make assessments of the mineral potential of their property without their knowledge or without their consent for the performance of such

assessments. EODMS may also raise concerns about "big brother in the sky"; the concern that individual movements might be monitored as the technology develops further. While to current practitioners such a concern seems far-fetched, public reactions to such threats are not always "rational".

The Privacy Act of 1974 was passed in reaction to the increasing threat to individual privacy by the collection and dissemination of personal information by federal agencies. It recognizes that computers and other "sophisticated information technology"(5-10) can contribute to this intrusion. Such technology might include satellites and other remote sensing platforms. Under the Privacy Act, an executive agency may not disclose any record from a system of records without the consent of the pertinent individual unless the disclosure falls within one of eleven enumerated exceptions. A "system of records" is defined as a group of records from which information is retrieved by the name of the individual or some other identifying number, symbol or identifying particular assigned to the individual.

Two of the exceptions relate to disclosure: i) for "routine use" compatible with the purpose for which the information was collected and ii) to a recipient who has provided written assurance that the record will be used solely as a statistical research or reporting record and that the record is to be transferred in a form that is not individually identifiable. These exceptions to the consent requirement might be applicable to the dissemination of data collected by an EODMS.

Among other requirements, an agency must publish annually in the Federal Register a notice of the existence and character of any system of records. Agencies are to establish rules of conduct for persons involved with the design, development, operation or maintenance of a system of records and establish appropriate safeguards to ensure the security of the records. In addition, agencies are required to give Congress and the Office of Management

and Budget notice of any proposal to alter or establish any system of records in order that the system may be evaluated with respect to impact on individual privacy and, among other things, separation of governmental powers.

A Privacy Protection Study Commission was established to "make a study of the data banks, automated data processing programs, and information systems of governmental, regional, and private organizations" (5-10) to determine what procedures have been adopted for protection of personal information.

An EODMS might fall within the Privacy Act if retrievable information pertaining to an identifiable individual were collected and disseminated. The parameters of the types of personal information covered by the Privacy Act await futher definition; if individually identifiable personal infor-tion is collected in an EODMS, measures must be taken to protect it.

In enacting the Privacy Act, Congress sought to protect individual rights including the rights to job opportunity, insurance, credit, and due process of law. Do large scale land use or land cover maps or low altitude photos of a person's land infringe on these rights? Is a computer map illustrating point sources of pollution an invasion of privacy? An EODMS could face many such challenges based on the Privacy Act, but before such questions are answered, the scope of the right to privacy may need to receive further definition.

CHAPTER 6. EARTH OBSERVATION DATA MANAGEMENT SYSTEM ALTERNATIVES

6.1 INTRODUCTION

6.1.1. Overview

In this chapter, several alternatives for operational EODMS systems are presented, taking into account both technical and institutional factors. We examine a small number of contrasting alternatives which illustrate the range of options available to decision makers. For each system alternative, the major characteristics are defined, and various system functions are assigned to specific hierarchic and jurisdictional levels in the system. The alternative is then evaluated according to a set of qualitative criteria, which includes system capacity, economy, responsiveness, flexibility, impacts, ease of implementation and interfacing. Finally, two predominantly public sector systems are identified as being most promising for detailed future system synthesis and assessment studies.

This analysis does not attempt to be exhaustive in enumerating possible system alternatives nor definitive in evaluating them. Rather, the work represents an initial effort to identify the most promising EODMS system concepts to serve state, regional and local users.

This chapter is organized as follows. Section 6.1.2 contains a discussion of the system functions to be performed and several constraints and assumptions under which we require the system to operate. System characteristics for which design choices must be made are identified in Section 6.1.3. Criteria for comparing and evaluating alternatives are stated in Section 6.1.4. Appendix G contains a brief description of the current experimental system for LANDSAT data and other related

activity which might influence EODMS development.

Table 6.1 contains a list of four major EODMS alternatives presented and discussed in Section 6.2. For each alternative, variations in certain system characteristics are considered.

Table 6-1

EODMS System Alternatives

Alternative	Descriptive Title
System A	An Evolutionary System Based Upon Present Institutions
System B	A Natural Resources Information System With Interpretation At A National Center
System C	A National Data System With Interpretation At Regional Centers
System D	A System Under Private-Sector Control

In Section 6.3 it is concluded that two predominantly public sector systems, derivable but somewhat different from the alternatives presented in Section 6.2 appear most promising for detailed future system synthesis and assessment. These alternatives are 1) an evolutionary system based upon present institutions and 2) a natural resources information system with regional processing centers. Although a system controlled by the private sector does not appear suitable for the primary system mission of delivering priority products to state, regional and local users, there should be many opportunities for private sector involvement in an operational EODMS controlled by the public sector. The chapter concludes with recommendations for future research.

6.1.2 System Functions

EODMS system alternatives are assumed to carry out a comprehensive set of functions, from data acquisition by satellite and other platforms to delivery of final products to users as illustrated in Figure 6-1. This system concept, which is consistent with delivery of priority products as developed in Chapter 3, is somewhat broader than that employed in several previous studies as discussed in Appendix E.*

Product production is preceded by data collection, correction, selection, enhancement, registration and interpretation. (See Figure 6-1). Storage, retrieval and dissemination involve storage of raw and processed data, entry of user requests for information, retrieval of data in the system, scaling and reformatting when necessary, physical production (i.e. printing or display) of the finished information products, and delivery to the user. System management encompasses data base administration, choice of information products, format specification and standardization, product scheduling, coordination of aircraft data acquisition, funding and staffing of EODMS centers, hardware procurement, planning of research and development, user education, modifying the system in response to experience and technical progress, and public and political relations.

*What we have called functions here reflects a decision about the scope of data services an EODMS might provide, as discussed in Chapter 5. We require the system alternatives to be capable of delivering some or all of the priority products of Chapter 3, to state, local and regional users. This does not preclude delivery of products in less finished form. (See Section 5.3 and Figure 6-1)

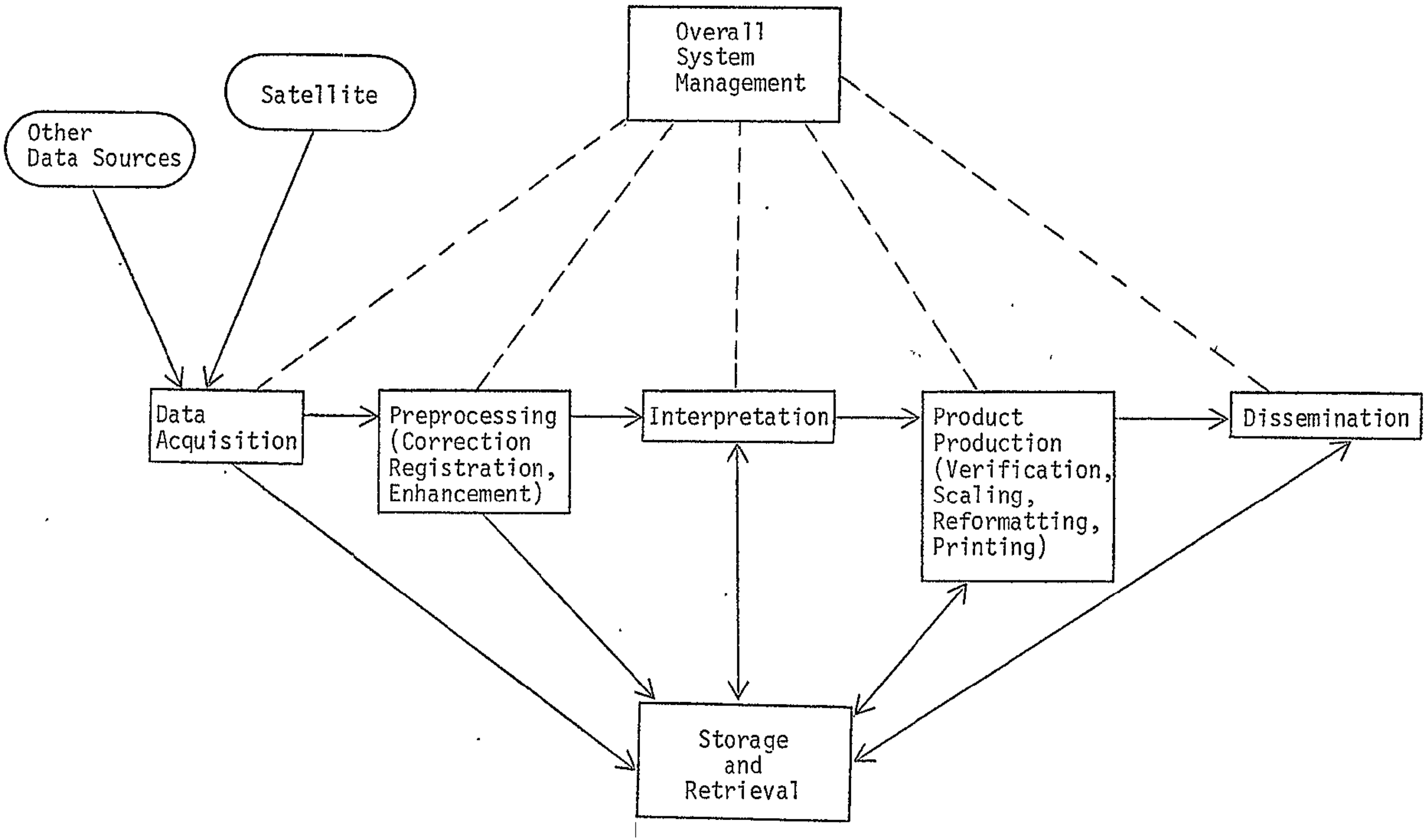

Figure 6-1: EODMS System Functions

6.1.3 System Constraints and Assumptions

We have placed several constraints and/or assumptions on the EODMS system alternatives discussed in Section 6.2 in order to limit the number of factors to be considered in system design. These include constraints on time frame: state of the technology, user community, product composition, platform use, method of interpretation, and geopolitical focus.

Time Frame: State of the Technology. The time frame of this study is 1980-1985. The scheduled launch date of the LANDSAT Follow-on is 1980. (6-1). Beyond 1985, technology which is not developed may play an important role. System alternatives in this study are based upon proven data processing technology and current remote sensing (RS) technology as well as on RS technology scheduled up to 1980. Later improvements in the technology are taken into account by including the ability of a system to adapt to changing technology within one of our evaluation criteria.

User Community. Meeting the needs of state and local* agency users is a central focus of this study. System alternatives also consider multi-state regional and federal-level users to a lesser extent. Private sector users are prominent in the "System D" alternative (See Table 6-1). The primary emphasis on state and local agency users is consistent with the scope of the data needs analysis (Appendix A) and the development of the priority products (Chapter 3).

Product Composition. Central Role of Priority Products. Each EODMS alternative is able to deliver some or all of the priority pro-

*Our data needs analysis also includes "sub-state" and "bi-state" regional planning agencies.

ducts identified in Chapter 3 to users on a regular basis in finished (interpreted) form. This specification is based in part upon the finding that the state and local user community typically lacks the capability for digital interpretation of satellite imagery. However, we recognize that some users may wish to access data prior to interpretation or in forms other than the priority products. Our system alternatives provide some of this flexibility.

The priority products are primarily in one of two forms: Maps or map overlays and digital representations of these maps for use as inputs to computerized geographic information systems. Most products are to be updated on a regular schedule, usually annually or less frequently. Certain products are needed irregularly, often on short notice; e.g., flood inundation area maps or forest fire maps. The systems are assumed to be able to respond rapidly to some but not necessarily all such irregular demands.

Platform Use. Multiple Data Collection Platforms. The EODMS alternatives make use of multiple data collection platforms for data acquisition. Data from several platforms are combined, along with other information already in the system, to produce a product with the desired accuracy. Ground truth must be established. For products based on automatic interpretation of data from remote platforms, adequate sampling from closer platforms is needed to train classifiers to recognize spectral signatures of features of interest.

Method of Interpretation. Both visual interpretation and automatic classification are assumed to occur in the system alternatives, although not always at the same location or jurisdictional level. As

a rule of thumb, the appropriate method for a given product will depend on the desired resolution and the format of the input data. For fine resolution products, e.g., two meters, features are usually identified by eye from photos. If coarser resolution (say 30 meters) is sufficient, the product would be derived mainly from satellite or high-altitude aircraft imagery. The results of Chapter 4 indicate that digitally-based interpretation of satellite data is roughly a factor of four less expensive than visual photointerpretation of aircraft data for priority production production (See Tables 4.21 and 4.22).

Geopolitical Focus. System alternatives are assumed to serve users throughout the United States. Users in other countries are not considered. We ignore effects on sensor complement, format specifications, cost sharing, etc. which might be present if U.S. satellites were part of an international system.

6.1.4 Characteristics of EODMS Systems

Several EODMS alternatives may be generated by making basic choices among key system characteristics. In this section, four major design factors are considered: 1) the scope or nature of the system data; 2) the character of the centers where the crucial function of interpretation is performed; 3) the distribution of functions among the national, state, and regional levels; and 4) the institutional mechanism under which the system operates.

6.1.4.1 Scope and Nature of Data

There are alternative ways of classifying EODMS systems based upon 1) the scope and nature of input data to the system, 2) the scope of the data retained as an integral part of the system, and

3) the data or information products which the system delivers. For example, in a previous report (6-2) we loosely classified data into three categories*: "Earth Observation" data** obtained by satellites and high altitude aircraft; "Natural Resources" data encompassing "Earth Observation" data along with low-altitude aircraft and ground survey data; and "Comprehensive" data including both "Natural Resources" data and "Socio-Economic" data such as census data and data on industrial activity.***

Our analyses in Chapter 3 and 4 indicate that systems which use Earth observation data will also need low-altitude aircraft data and ground truth to produce the 27 priority products we have derived from our analysis of state and local agency data needs. Some of these products require socioeconomic data as well as natural resources data as inputs. Others require no satellite or high-altitude aircraft at all.

If all of our hypothetical system alternatives are required to produce a fixed menu of priority products using the same input data, then clearly the scope and nature of data would be a constant. We choose instead to treat this system characteristic as a variable be-

*A fourth type, which would provide individual data on employment, education, political activity, and the like, has been explicitly ruled out of consideration by the EODMS team on the grounds that it would provide access to sensitive information to an inappropriately broad range of agencies whose basic missions are resource management.

**Perhaps a better phrase is "synoptic data."

***Even here, the terminology lacks precision. Urban land-use maps are not "natural resource" data per se but we include them in the natural resource category because of their utility for natural resource management.

cause political and institutional constraints concerning the scope and nature of the data will be of great importance in implementing a system, and we wish our alternatives to be broadly illustrative of a range of realistic system options.

The evolutionary system alternative (System A) and the privately controlled alternative (System D) build upon data from the present experimental LANDSAT system (based essentially on what we have called "Earth observation" or "synoptic" input data) augmented by other input data to accomodate production of some or all of the priority products. In System B, the input data, the data retained as an integral part of the system, and the information products which the system delivers encompass the field of natural resources information. Socioeconomic data is used in System B as input to natural resources information products but is not delivered by EODMS to users or incorporated for its own sake as an integral part of the EODMS system. In System C, the data base includes both natural resources and socioeconomic data. Products are available from System C, for example, concerning population, labor statistics and industrial activity as well as land use and topographic maps. In all four alternatives, we exclude Department of Defense data and information products as an integral part of the system. Further discussion of the scope of data is included in Section 5.3.

6.1.4.2 Character of Processing Centers: Disciplinary* or Multidisciplinary

An important factor in clearly identifying major EODMS alter-

*We use the word disciplinary to indicate the domain of one mission-oriented agency, as opposed to a subject matter area such as chemistry or biology. Thus, the NOAA weather system is an example of a "disciplinary" system. The world "application" might be a better choice than "discipline."

natives is the character of the centers where processing and interpretation take place. Three of the four major alternatives are based on: 1) interpretation within disciplinary, mission-oriented agencies like USDA and USGS (System A); 2) interpretation at a single, multidisciplinary center (System B); and 3) interpretation at regional, multidisciplinary centers (System C). The character of centers for the fourth alternative (System D) is not specified.

Although the EODMS alternatives we are considering will serve a user community over a range of disciplines, the interpretation centers may be associated with a single discipline. Each separate product might be assigned to the mission-oriented agency whose staff is most knowledgeable in a particular subject field (e.g., forestry, geology, hydrology. . .) relevant to the themes of the given product. Such an approach is consonant with current planning and information system development activity in several federal agencies such as the Department of Agriculture, the Environmental Protection Agency, and the Bureau of Land Management.

Alternatively, a single, multidisciplinary center could produce the entire range of products for a given geographic area, employing or contracting with experts with a diversity of backgrounds -- geologists, computer scientists, biologists, meteorologists, etc. These experts might be people who would continue to be employed by existing agencies, but would be detailed or assigned to the multidisciplinary center. Cost calculations in Chapter 4 indicate that major economic benefits can be realized by sharing facilities, equipment and skills among processes for producing priority products at a multidisciplinary center (See Table 4.23).

Multidisciplinary organization of processing, while more complicated to implement, would allow better sharing of hardware, data, and expertise among the various products. Also, irregular requests for special products and occasional requests from inexperienced users would be easier to accommodate. However, a major system breakdown might inconvenience a larger community of users. This effect might be minimized by providing enough slack capacity for emergencies.

6.1.4.3 Distribution of Functions: System Configuration

System configuration refers to the geographic and/or jurisdictional level at which system functions are performed, and defines the overall shape of the system in conjunction with the character of the processing centers. Functions may be performed at a national multidisciplinary EODMS center (see System B), at national centers operated by disciplinary agencies (USDA, USGS, EPA, BLM, etc. (System A), at multidisciplinary or disciplinary regional centers serving multistate regions (System C), at state Earth Observation data user centers, or at state user agencies.

The regional center concept appears to be a reasonable compromise between national and state-level processing. In general, the larger the center, the better it will be able to use the largest and most efficient technological systems at full capacity. On the other hand, the more centralized the processing centers, the more remote they are from firsthand knowledge of local conditions as well as from users. These two opposing effects of scale are weighed briefly in

Section 4.4.4.*

6.1.4.4 Institutional Mechanism for System Management; Other Factors.

A national public sector EODMS might be placed under the control of an independently funded new federal agency with full control over all EODMS components (See Systems B and C). Alternatively, EODMS authority might be vested in a federal interagency council which coordinates the efforts of autonomous participating agencies (System A). In these predominantly public sector systems, private sector involvement occurs through contracts to perform certain functions. The mechanism of a private EODMS corporation, analogous to COMSAT, which would own satellites, acquire data, and deliver finished information products to both public and private sector users is considered in System D.

Several other factors influence the design of an EODMS, including costs, pricing policy and staffing. These factors are discussed briefly in connection with the specific alternatives presented in Section 6.3, as well as in Chapter 5.

*Our calculations indicate that the priority product processing load for the five-state study region can be accommodated by a single third-generation computer (See Section 4.4.4.) A single national processing center for the entire U.S. presently introduces no great economies of scale in computer costs because producing all the priority products for the entire U.S. would exceed the capacity of the largest and fastest commercially available computers. Although national processing might fare better with the development of array processor computers such as STARAN, computer costs represent only a portion of the total processing costs. At the other extreme, a computer located at a state center would not be utilized to full capacity unless the state were large and well-financed, unless the computer were shared with other state agencies for other purposes, or unless the computer were small with accompanying high unit costs.

6.1.5 Criteria for Evaluating Alternatives

We have identified a number of criteria to evaluate the four EODMS alternatives. The criteria and the questions they raise are as follows:

1) Capacity and Economics. Is the system likely to have the capacity to produce all the priority products with the required timeliness and accuracy? What are the economies or diseconomies to be expected from each system?

2) Responsiveness and Flexibility. Will the system be sufficiently responsive to users? Can users whose data needs are not initially well defined be satisfied? Can all information present in the system be speedily accessed when necessary? Can the system satisfy new users as well as established users? Will the system be sufficiently flexible to: provide special products to meet one time or irregular data needs; accommodate improvements in the technology of remote sensing, data processing hardware and software; adapt to changing needs for information; and evolve towards production of more specialized information products as use increases?

3) Interfacing. Will the EODMS data base be able to interface readily with external systems? Can existing information systems of participating agencies be incorporated in the system? Will the system provide output in formats desired by users?

4) Implementation and Impacts.* What are the obstacles to implementing each model? Will there be large front-end capital costs? Will agencies resist having some of their functions pre-empted? Will they resist assuming additional functions or reorganizing? Will there be problems getting sufficient funding for the system to plan its evolution in an orderly way? Are legal challenges likely? Is a phased implementation more likely to succeed than one involving major change? Can a go-ahead decision be made before potential users commit themselves to full participation? What are the economic, social and political impacts to be anticipated for each alternative?

*Although economic, social and political impacts are listed in the evaluation criteria, they are not considered to any great extent for some of the alternatives. For further consideration of impacts, see Chapter 5 of this report and Chapter 7 of Reference (6-2).

6.2 FOUR EODMS ALTERNATIVES: CHARACTERISTICS AND EVALUATION

The characteristics of four hypothetical, operational EODMS alternatives are summarized in Table 6-2. In the following section, each alternative is discussed and evaluated based upon the criteria and questions raised in Section 6.1.4. Variations on each main alternative are also considered. Key features of each system are depicted in Figure 6-2.

6.2.1 An Evolutionary System Based on Present Institutions* (System A)

The first model, shown in Figure 6-2A is based on existing federal disciplinary agencies and is heavily oriented towards satellite and high-altitude input data. Federal overall management authority is vested in an interagency council as recommended by the Space Applications Board (6-3). The EODMS interagency council reviews the data needs and information systems of national, regional and state agencies which participate in EODMS, decides on product characteristics, and assigns production of each product to the existing federal agency it deems most appropriate.

6.2.1.1 Characteristics of System A

6.2.1.1.1 Scope of Data

This system produces information products based primarily on satellite and high-altitude aircraft input data. These products also require low-altitude aircraft and ground truth inputs. (See Table 4.9) Products based primarily on low-altitude photography or ground survey continue to be produced under present agency arrangements but are gradually incorporated into System A.

*See Appendix G for a description of current federal systems relevant to EODMS development, including the present system for LANDSAT data dissemination.

Table 6-2:

Summary of EODMS System Alternatives

Alternative	Key System Characteristics	Evaluation
System A: An Evolutionary System Based on Present Institutions	Control: Public Sector Management: Federal Interagency Council Configuration: Processing at National Disciplinary Centers Scope of Data: Principally Satellite and High-Altitude Aircraft Augmented to Permit Some Priority Product Production Principal Variation Considered: Some State-Level User Centers	Federal Interagency Council fits current government structure; interagency arrangement may lack cohesion, responsiveness; national disciplinary centers may prove cost-inefficient; state processing variation beyond means of most states
System B: A Natural Resources Information System with Interpretation at a National Center	Control: Public Sector Management: New Federal Department of Natural Resources Configuration: Processing at National Multidisciplinary Centers Scope of Data: All Data Pertaining to Natural Resources Management Principal Variation Considered: State Branches of National System Perform Some Functions	Federal Natural Resources Agency provides suitable focus for information products and coherent management. Takes major government effort to implement. Processing at multidisciplinary centers more cost-effective than at disciplinary centers. National centers may prove unresponsive to state and local concerns, with relatively little cost advantage over regional or large-state processing.
System C: A National Data System with Interpretation at Regional Centers	Control: Public Sector Management: New National Data Agency Configuration: Processing at Regional Multidisciplinary Centers Scope of Data: System B plus Socioeconomic Data Principal Variations Considered: 1. Some State-Level Processing 2. Federal Interagency Management	Cost-effective, coherent management possible; having a "super" government information agency likely to prove threatening and politically unacceptable; multidisciplinary regional processing seems to strike right balance in terms of technical capability, economics and responsiveness to users.
System D: A System under Private Sector Control	Control: Private Sector Management: New, Congressionally-Chartered "INFOSAT" Cooperation Configuration: Flexible Scope of Data: Principally Satellite and High-Altitude Aircraft Augmented to Permit Some Priority Product Production Principal Variations Considered: 1. Two parallel systems: Public serving public sector, private serving private sector 2. System under public sector control with heavy private sector involvement	Private sector system not likely to have sufficient incentive and reward for servicing "soft" state, local, regional user markets. Certain traditional government functions would need to be curtailed. Private sector likely to have major involvement in processing for large private-sector users and to perform several functions in a public sector system. These functions should be carefully delineated to avoid possible conflicts of interest.

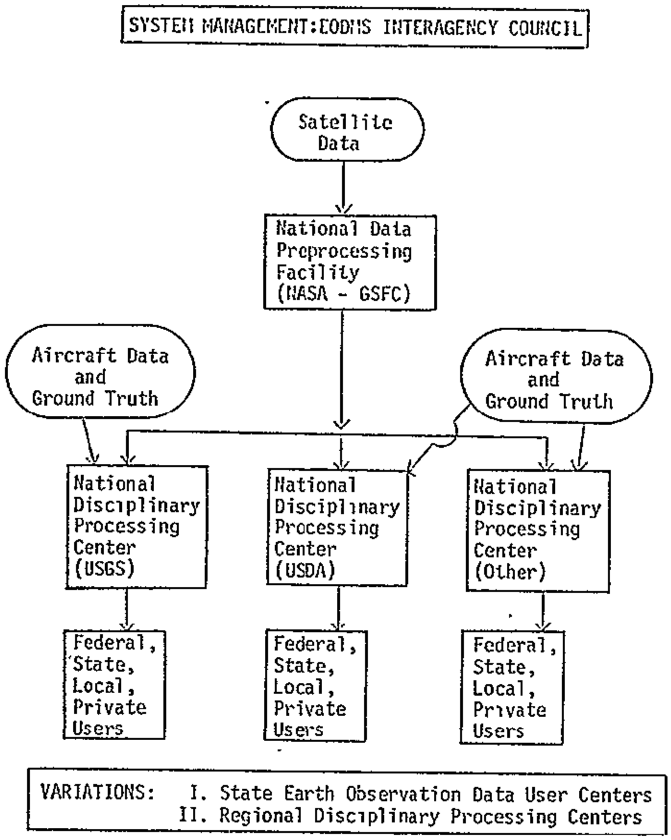

Figure 6.2A. An Evolutionary System Based On Present Institutions

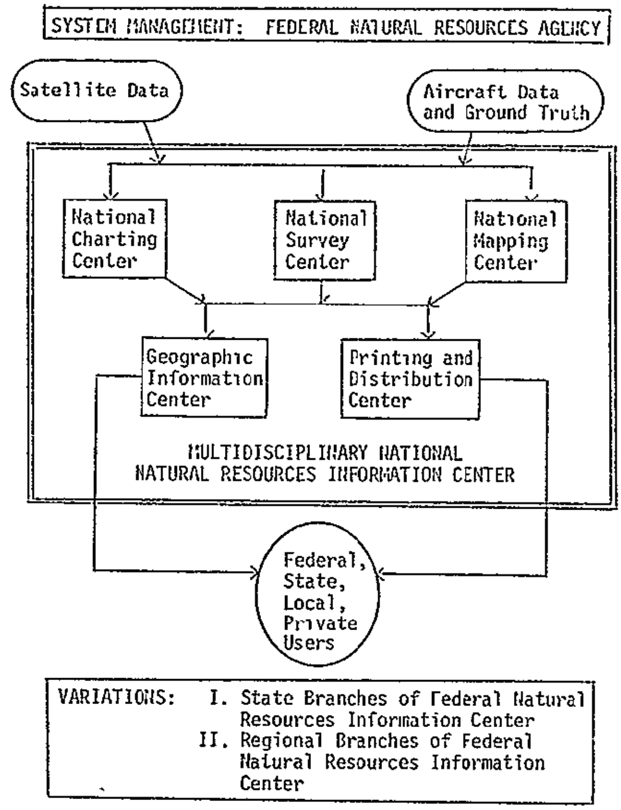

Figure 6.2B. SYSTEM B. A Natural Resources Information Center with Interpretation at a National Center

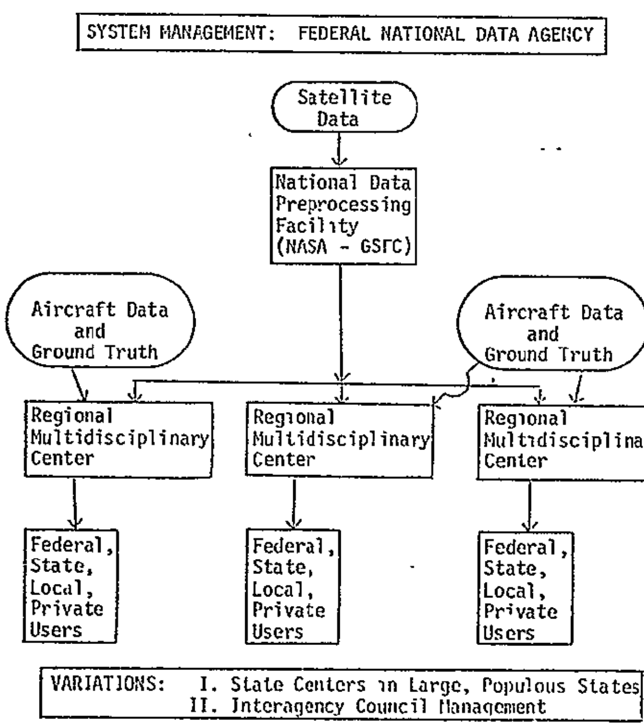

Figure 6.2C. SYSTEM C. A National Data System With Interpretation at Regional Centers

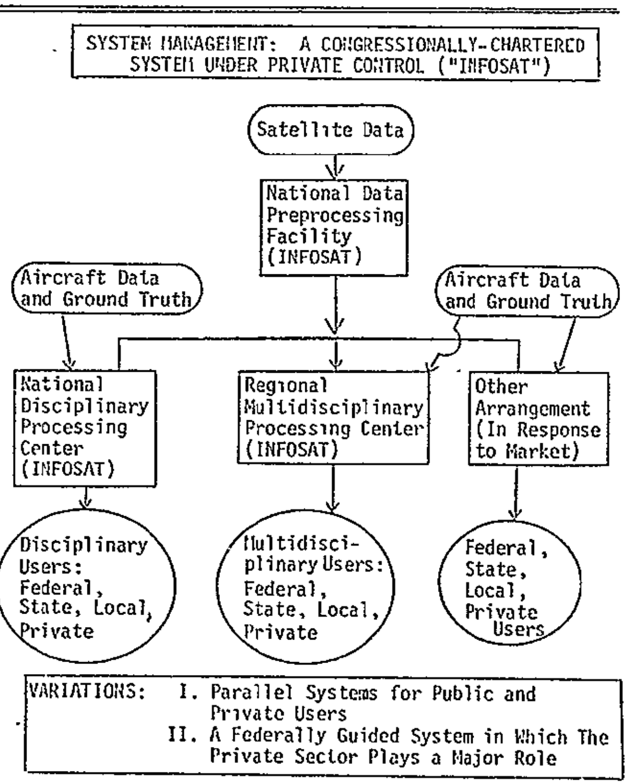

Figure 6.2D. SYSTEM D. A Congressionally-Chartered System Under Private Control: INFOSAT

6.2.1.1.2 Character and Configuration

Acquisition of data from space platforms remains the responsibility of NASA. The data are corrected radiometrically and gemetrically at NDPF*; then archived, screened and sent to the mission-oriented federal agencies which perform interpretation. These agencies, such as USDA, USGS, and EPA acquire high-altitude aircraft imagery, and low altitude and ground truth observations as necessary for sampling, training and verification. Another important class of inputs is pre-existing information for base maps or as aids to faster classification. The producing agency retains its old products in its files. Products of other agencies are located by an up-to-date, master computer index at the National Cartographic Information Center (NCIC) (See Appendix G) which is expanded to perform this function for all the agencies in EODMS.

The burden of interpretation falls on national centers within the existing, mission-oriented agencies to which the products are assigned, such as the EROS Center of the Department of the Interior. The various inputs are brought together, registered and interpreted by specialists on the staff of the producing agency. Interpretation is manual, machine-aided, or automatic, depending on the product and the state of the art. Users outside of the producing agency receive products in useable, finished form as maps, tables or overlays as well as raw data if they so desire.

Products such as maps are printed by the Government Printing Office, by a separate federal map printing center,** or at the national

*To a greater accuracy than NDPF now achieves.
**For example, the USGS Mapping Center at Reston, Va., expanded to accommodate the increased demand for services.

disciplinary centers, using using automatic hardware which converts classified CCT's into hard copies of overlays or maps. The EODMS Council decides which option best satisfies the need for timely dissemination of products and for meeting federal accuracy standards.

6.2.1.1.3 Staffing, Funding, Sector Mix

The EODMS Interagency Council is served by a permanent staff, divided into functional groups for land mapping, geodesy and surveys, nautical charting, special purpose mapping, imagery collection, and information systems. This arrangement is in line with an option described in a 1973 report of the Federal Mapping Task Force on Mapping, Charting, Geodesy and Surveying. (6-4)

Funding of this predominantly public sector system is provided by one or more of several mechanisms: 1) The EODMS Council directly receives funds from the federal budget, in effect making it a quasi-independent agency, in which national, state and regional agencies are represented; 2) A state utilizes revenue-sharing funds to pay for information products using the state budgeting process to set priorities for the products it requires; 3) The product producing agencies such as USDA or USGS receive budget increases to cover costs of producing new products; or 4) State agency users pay for products out of their individual budgets.

This system alternative, which assumes a predominantly public sector system and minimal institutional change, contains some system functions which could be carried out in the private sector. The fact that interpretation is carried out in existing national disciplinary centers could restrict the ability of the system to satisfy sudden demands for special products. Opportunities exist for the private sector to perform such special purpose image interpretation.

Data needs in the private sector, where very current information is at a premium, are unlikely to be met fully by government products, which could be slower and more complete than what private users would want. Private groups could take this opportunity to acquire very timely, raw remote sensing imagery from the government, interpret it, and market it to interested private users. Large corporations currently acquire raw data from the government and interpret it for their own use.*

An additional role for the private sector is the development of improved image processing technology and sensor technology under government contracts. This includes hardwired computer circuitry to execute particular algorithms rapidly as well as display and output devices.

6.2.1.2 Evaluation

6.2.1.2.1 Capacity and Economics

Development of the capability to produce all the priority products would involve expansion and perhaps reorganization of the agencies charged with such activity. Each producing agency would have to have access to sufficient computer processing and storage capacity to provide for its set of products over the entire nation.** Sufficient staff would have to be trained in image interpretation to supply the human side of the processing load. Products could be implemented one-by-one as the processing staff gains in experience and algorithms

*See Section 5.4 for an examination of policy issues raised by this practice.

**Some agencies do not normally serve all 50 states. For example, the Bureau of Land Management is mostly concerned with the western states and Alaska.

are perfected. Producing an initial version of each product will be much slower and more costly than regular updates thereafter, so these start-up burdens should be staggered.

This system has the advantage of building upon existing agency capability and investments. However, some diseconomies could also arise. The distribution of responsibilities among several autonomous units might make good coordination of inputs like low-altitude aerial photography unlikely. Similarly, sharing of expertise or equipment among the staffs of the various producing agencies will not occur as easily as it could in a multidisciplinary center. Also, the varying seasonal rhythms of some of the priority products will be harder to exploit, whereas a multidisciplinary center could shift resources from agricultural to geological products, for example, during times of the year when vegetative ground cover is absent.*

Processing at national centers means that the distance from producers to local users is considerable. Thus, state-level users might have difficulty communicating effectively with the producing agencies, and could play a very passive role.** Furthermore, since many large-scale products might be used more by local and state than by federal agencies, large quantities of information might nave to be moved long distances.***

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*For example, Level II Land-Use (urban) maps, topographic maps, flood prone area maps and surficial material maps require winter imagery whereas spring and summer imagery are needed for vegetation maps, forest stand maps, and lake trophic status maps. Scheduling of processing will be to some extent related to the season of data acquisition.

**This may be less likely for agriculture where an extensive federal network reaches out to state and local users than for other sectors where there is no established national infra-structure.

***The role and costs of telecommunications in EODMS product dissemination requires further study. See Ref. (6-5).

Finally, the interpretation centers might not have the detailed knowledge of local terrain which is needed in visual photointerpretation or as ground truth in automatic interpretation.

6.2.1.2.2 Responsiveness and Flexibility

The responsiveness of the system to user needs will be very much dependent on the composition of the EODMS Council. If the Council only includes representatives of federal agencies as is common practice in federal inter-agency councils, then the system is likely to be unresponsive to needs at the state, local and regional level. The system serving federal, state, regional and local agencies should have representatives of all these agencies on the managing body.

The inter-agency structure may be relatively inflexible and unresponsive to irregular, aperiodic data needs on the state and local level. If satisfactory input data are not available, users with a special need for information could contract for data acquisition, but interpretation would remain a problem. Users would probably have to shop around at universities or in the private sector for people with the appropriate knowledge, develop possibly uneconomic in-house interpretive capability, or be faced with long delays while the EODMS Council decides to whom to assign the task.

6.2.1.2.3 Interfacing

Users could access information through USDA or USGS assistance centers. State branches of NCIC* could assist state level users in locating regular priority products and in meeting nonrecurring or

*NCIC state branches are currently in the planning stage. (See Appendix G)

irregular data needs. EODMS could respond to special requests by assisting users in obtaining and interpreting information, or by producing a special product.

The interfaces described above have the advantage of building on existing relationships which federal mission-oriented agencies have developed with state users. However, for some state agencies in some fields, these interfaces may not be well developed. Additional efforts to beef-up state agency capacity may be required. (See Section 6.2.1.3)

Interfaces also have to be worked out with computerized geographic information systems which are developing at the state, regional, and federal levels. (See Ref. 6-6 and Appendix F) Federal systems tend to reflect the interests of mission-oriented agencies, whereas some state systems tend towards aggregation across agencies. The former trend is favorable for the interfacing with the System A EODMS concept, whereas the latter trend would favor System B or C.

6.2.1.2.4 Implementation and Impacts

Implementation of this system alternative appears to involve less administrative and political effort than creating a new agency, at least in the short run. Products currently being produced would continue under present auspices, although format and scheduling might be revised to take into account a better coordinated and larger user community.

It may be desirable to begin implementation with a nationwide survey of data needs by the national EODMS Council as the basis for product specification. Potential users would be encouraged to commit themselves to receive finished products regularly. Feedback from

state level users regarding timeliness, accuracy, format, etc., would be sent to the producing agencies, which would modify their procedures as appropriate, subject to oversight by the EODMS Council.

Implementation of this alternative is a political act requiring initiatives from one or more sources. A Space Applications Board report envisions a National Space Applications Council established by Congressional statute as the recommended institutional mechanism during a transitional period from the experimental to the operational phase. (6-3) Federal interagency rivalry and the reluctance of OMB to support sustained government involvement in Earth observation satellite activity have served to inhibit implementation of an operational system. Assurance of continuity of data acquisition by NASA through future satellite launches is essential during the implementation as well as operational phases.

6.2.1.3 Variations on System A

State Earth Observation Data User Centers could be established at locations near many state agency offices and given responsibility for locating information in the system; user education and recruiting; central storage for all state information in the EODMS data base;* coordination of low-altitude data acquisition within the state for all EODMS products; limited interpretation for special data products; and, perhaps, devices to produce hard copies of maps and overlays from digital data for users.

Advantages of such centers over a system with only national centers

*Detailed information which is not of much interest at the national level could be archived here.

include enhanced accessibility, fairly complete one-stop services, an improved channel for user feedback to the system regarding product suitability, more effective coordination of inputs, and enhanced capability to deal with irregular data needs.

The ability of an individual state to provide some or all of the services described above depends upon its resources. Large, populous states such as California and Texas might be able to provide a broad range of services, whereas smaller states might be severely limited. A regional approach to serve smaller states might be required.

Thus a second variation on System A distributes the task of interpretation to regional disciplinary centers of the production agencies. Some agencies already have regional offices, such as the four USGS mapping centers. USDA, which has a presence in every county in the country, has four computing centers which belong to distinct divisions within USDA. (6-2)

Determining the optimum number of regional disciplinary centers involves several tradeoffs. As the number of centers in each discipline increases, the responsiveness to local conditions and knowledge of the local terrain will increase. However, each center has a smaller product load which means less efficient computer utilization.*

We believe that at least four regional centers would be required to be responsive to local conditions, but that a disciplinary agency producing only a subset of the priority product list might be unable to use the largest and most economical commercially available computers at full capacity. This suggests that multidisciplinary

*The latter problem might be overcome by time-sharing or computer communication networks. This possibility needs to be examined.

regional centers may be preferable to disciplinary centers. More work is required to determine the optimum size, location and scope of services of a regional center.

6.2.2 A Natural Resources Information System With Interpretation at a Multidisciplinary National Center (System B)

In this section, we describe and analyze a system which integrates satellite data, high and low-altitude photography and ground survey information to produce a full spectrum of information products for use in natural resources management. We place the system under a new federal natural resources agency.* Interpretation is performed in a multidisciplinary center at the national level. We also consider a variation in which some interpretation is performed at state centers. Figure 6-2B depicts the main system elements.

6.2.2.1 Characteristics of System B

6.2.2.1.1 Scope of Data

This system produces all information products of use in the natural resources field, derived not only from satellite and high altitude input data but from low altitude data and ground surveys as well. Included as part of the data base are all domestic mapping, cartographic and survey information from all platforms acquired by the federal government or with federal funds, with the exception of data and products of primarily a socioeconomic nature such as those delivered by the Census, and those of the Defense Mapping Agency.

*An OMB Federal Mapping Task Force report recommended in 1973 that selected functions and mapping programs be consolidated under a new strong central mapping agency (6-4). We build upon this concept in developing this alternative, but exclude military products from all EODMS alternatives.

6.2.2.1.2 Character and Configuration

A key element of this system alternative is a multidisciplinary National, Natural Resources Information Center with multiple data inputs and full interpretation and processing capability. The center is subdivided into five management units*: 1) a National Charting Center to provide civilian aeronautical charts, nautical charts and marine geological information; 2) a National Survey Center to maintain the vertical and horizontal National Geodetic Networks and cadastral (boundary) information for all application areas; 3) a National Mapping Center to produce topographic and other land area maps and provide cartographic services; 4) a Geographic Information Center which serves as a current, centralized source of information for all collected and processed imagery, maps, etc. and 5) a Printing and Distribution Center which would print and deliver products to users.

Geographically, not all of these functions are performed at the same location. The Printing and Distribution Center has several sales outlets. However, several of the processing and interpretation functions benefit from sharing of resources and facilities.

All raw data flows into one of the three centers, (Charting, Mapping, Survey) where it is stored and processed. The Geographic Information Center (GIC) has access to all raw and finished data. The GIC can also access aggregated, non-spatial natural resource information within the overall natural resources agency and is linked to other data bases such as the Census, with a consistent referencing scheme developed. Requests from users for information are channeled through the GIC. The Printing and

*This arrangement follows the recommendations of the 1973 Federal Mapping Task Force Report. (6-4) It may be that the proposed organization of management units is not the optimum for natural resources management information products.

Dissemination Center (PDC) has its own printing hardware because of the large product load, because high accuracy map printing requires specialized technology and because reliance on the Government Printing Office or other externally managed printing might result in delays and quality problems.

6.2.2.1.3 Management, Staffing, Funding

This EODMS system alternative is under the management of a new Natural Resources Information Agency within a newly created Federal Department of Natural Resources*. A plan for reorganization involving creation of such a department was put forward in the early 1970's but was abandoned. Prospects for reorganization have improved as of late 1976, although energy may be the main focus.

Managerial responsibility is vested in a Plans and Requirements staff whose functions are to:

1) assemble, review, rank in priority and promulgate domestic natural resource information products;

2) continually review product specifications;

3) assist users in formulating information product requirements;

4) seek out and eliminate duplication, waste, and gaps in service.

Initially, staff is drawn from existing agencies into the new natural resources agency.** Within the mapping, charting and survey centers, staff can be flexibly deployed in accordance with changing requirements.

*An alternative would be the creation of an independent agency. (See Ref. 6-3)
**Specific suggestions for agency transfers are given in the Federal Mapping Task Force Report (6-4).

Funding is provided by a combination of budget transfers from existing agencies and new federal appropriations. Users pay for some or all of the product production costs. Hopefully, elimination of overlaps and duplication leads to savings which help support the new initiative. In 1973, some 39 government agencies were producing maps. (6-4)

6.2.2.2 Evaluation

6.2.2.2.1 Capacity and Economics

This EODMS alternative can be designed with the capacity to deliver priority information products on a regular basis, while taking advantage of economies made possible by putting the activity under the auspices of one unified agency. The multidisciplinary national center is likely to make better use of both human resources and large-scale equipment than the several national disciplinary centers of System A. As is pointed out in the Federal Mapping Task Force Report (6-4): "Expensive equipment that is most effective at full capacity, such as computers, printing presses and plotting instruments will be used more efficiently."

The interdisciplinary staff should permit shifting resources to special products when needed, assuming sufficient capacity is set aside for this purpose. Thus, it should be possible to meet requests for specialized information in a timely manner.

6.2.2.2.2 Responsiveness; Flexibility

A system based on a natural resources agency should be able to respond more effectively to Congress and the executive than an interagency council. Planning of multi-stage, multi-platform products can

reduce delays since all resources are under a single management. Access to information by federal agencies which had previously gathered their own data would now be through a single center and information could be more readily shared among agencies. However, this may be less desirable than the current arrangement for agencies that now do their own data gathering and interpretation. Furthermore, while this all sounds good in theory, in practice the situation may be very much different.*

Ideally, under System B management, the overview of all information products allows considerable reduction of redundancy. Responsibility is well-defined, and gaps in information product production can be identified and filled. Central management allows coherent overall planning in response to changing data requirements and evolving processing and sensing technology. For example, as the U.S. moves to the metric system, a smooth transition could be far easier than if product responsibility were dispersed. This favorable view of centralized management overlooks the possibility of squabbles arising over product specifications and other human factors.

Service to state and local users could be improved, since a unified management could systematically survey data needs. On the other hand, the centralized managers might tend to deemphasize state and local data needs relative to those at the federal level. Similarly, the accuracy and utility of information products from the state and local users' point of view may suffer. The pitfalls of excessive centralization might be avoided by strong user involvement in system management or more decentralized processing. (See Variations, Section 6.2.2.3)

6.2.2.2.3 Interfacing

Problems of interfacing at the federal level might be much reduced

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*A less favorable scenario might emphasize that replacing one bureaucracy (or bureaucracies) by another (larger) one doesn't necessarily improve things.

under a single natural resources information agency than under the current fractionated federal interagency arrangement. Interfacing among federal, state, regional and local levels could be simplified if natural resources agencies existed at all these levels.

6.2.2.2.4 Implementation and Impacts

The creation of a unified natural resources information center under a new Federal Department of Natural Resources implies a major government reorganization. Thus, implementation of such a system would appear to be far more difficult to bring about than a system built on present institutions. However, if the new administration does move ahead with plans to reduce the number of government agencies and reorganize the government, then the prospects for implementation of this alternative could improve significantly. Implementation could involve a very critical transition period in which elements of programs for existing agencies are moved over intact to the new agency with programs being gradually evaluated and modified to fit the new conditions.

In the absence of the establishment of a Department of Natural Resources, the establishment of a natural resources information system might still be pursued using one of three management options: 1) an interagency council (See System A); 2) designation of an existing federal agency (say, NASA) as the lead agency; or 3) creation of a new, independent natural resources information agency within the executive branch of government. Difficulties associated with these latter two options are discussed in the Space Applications Board report. (6-3)

Somh difficulties that can be anticipated for this model with its national multidisciplinary center involve the extreme centralization of

processing. A national center would be located very far from ground truth. Intimate knowledge of local terrain, which can be very helpful in visual photointerpretation, would be hard to acquire for the whole country. Ground survey data and aerial photography would have to be transmitted to the national center for interpretation, and then back to state and local users. A considerable amount of personal travel from one location to another would be required as well.

For priority products based on digital interpretation of space and high altitude data, the processing burden to serve the entire nation might exceed the capacity of the largest commercial computers now available, according to our calculations in Chapter 4. A national multidisciplinary center would have to employ several CDC 7600's, full time, for example. Moreover, computer capacity would be needed for functions other than interpretation, such as access and retrieval of products, search of indices, payroll, data base management, and supervisory programs. Some of the problems associated with centralization may be ameliorated by moving some of the interpretation functions to the state or regional level.

It is likely that a unified, public-sector natural resource information system and center could provide more cost-effective information than is now available to aid in making better decisions about management of natural resources.

6.2.2.3 Variations on System B

A variation of this model involves establishment of Natural Resources Information Center branches in each state, in order to reduce the processing burden on the national center, and bring the system closer

to ground truth and to users. These state branches remain under federal agency control but they consult closely, on a weekly basis with state users. They perform the functions described in Section 6.2.1.3 for State Earth Observation Data User Centers, and also perform visual photo interpretation for high resolution products, utilizing knowledge of local features. Such knowledge also helps in choosing training samples for satellite-based products. Additional administrative overhead is necessary if state centers are added but this might be offset by the reduced need for data transmission.

It is likely that proximity to local features will improve product accuracy, and proximity to state level users will improve timeliness, user education, and tailoring of products to user needs. Some ground truth information might also flow into the system from state agencies. Sampling inputs from low platforms needed for proper interpretation of remote sensing imagery— would still need to be transmitted to the national center. Depending on the economics of map printing technology, interpreted imagery might be sent to a central location for printing before delivery to users. Alternatively, state Natural Resource Information Center branches might have their own printing hardware.

Other variations of the above arrangement readily come to mind. The concept of regional centers serving groups of small states is developed more fully in Section 6.2.3. Under a new Department of Natural Resources, the state centers need not be under federal auspices but could be state run or operated by organizations under shared federal-state management. Finally,

if a Department of Natural Resources is not created, the various system functions could be divided among existing agencies. For example, NASA or USGS might take over the national center functions involved in creation of complex products using digital processing of Earth observation data, whereas the states would perform visual photointerpretation.

6.2.3 A National Data System With Regional, Multidisciplinary Centers (System C)

Figure (6-2C) illustrates a predominantly public sector system which differs from Systems A and B in two principal respects. First, interpretation is performed at multidisciplinary regional centers which serve groups of states.* Second, the system includes not only the full spectrum of natural resources information available in System B, but also incorporates traditional socioeconomic data under the auspices of an overall National Data System.

6.2.3.1 Characteristics of System C

6.2.3.1.1 Scope

The scope of information included in this system is natural resource information derived from all platforms along with socioeconomic data. Traditional data from the Bureau of the Census and the Bureau of Labor Statistics can be delivered to users from the same output centers as the priority products.

*Some of the discussion in this section centers on a region of the size and scope for which we have analyzed priority product production in Chapter 4, namely our five-state study region. We do not consider in detail the optimum size or configuration of regions served by regional centers. Factors to consider in such an analysis include location and service region of existing federal agencies as well as area, population and product requirements. A large, populous state might well be a region unto itself. Further work is required to specify optimum regional groupings.

6.2.3.1.2 Character and Configuration

As illustrated in Figures 6-2C, inputs from various platforms flow into regional multidisciplinary centers (RMC's) where interpretation is performed, and raw data and finished products are stored. The regional centers provide information products not only to state, local, and private users, but also to federal agencies which receive data for each region from the respective RMC. Space data is preprocessed by NASA at NDPF, in accordance with a study by Aeronutronic - Ford which indicates that central preprocessing (correction and filtering) is preferable to distributing data reception and preprocessing to regional centers*. (6-5)

NDPF can also have a quick-look capacity, producing uncorrected imagery rapidly which is sent quickly to users for whom timeliness is more significant than resolution, e.g., for fire and flood monitoring.** Most of our priority products have far less stringent timeliness constraints, typically with update cycles of a year or longer.

Data from other platforms, such as aircraft, are input directly to the RMC's. A small fleet of high altitude aircraft, carrying advanced sensors, serve the national EODMS on a full-time basis. They are deployed among the regions under central control according to the national distribution of cloud cover. Within each region they are coordinated by the RMC which operates

*In Chapter 4, for purposes of cost comparison, we have sited preprocessing at the regional center and included its costs in product production costs. In any event, preprocessing is a small part of the total system cost.
**Alternatively, the regional centers might have quick-look capacity.

its own low-altitude aircraft or has access to them under long-term private contract, so that delays in arranging data acquisition are minimized. This arrangement allows the RMC to plan flights taking into account the input requirements for all the priority products. Ground level surveys are performed by teams from local, state or national agencies in cooperation with the RMC.*

The ability to coordinate low and high-altitude data acquisition, along with the multidisciplinary nature of the processing can be important factors in reducing product costs (see Chapter 4). For example, geologic maps which can utilize ten-meter resolution, high-altitude aircraft imagery could benefit from the imagery flown for orthophotoquad production. This same imagery could also be useful in vegetative cover mapping and Level-II land use mapping. Acquisition of a common store of ten-meter, high-altitude aircraft data allows more effort and money to be directed to better sampling at low altitude to refine each product.

The inputs from various platforms are combined with data on file and interpreted. The RMC stores raw data, finished products**, and intermediate and by-products such as enhanced and differenced imagery, records of spectral signatures, etc. Finished products in the form of digital tapes and maps are transmitted from the RMC to users at all levels. Depending on the economics of high-quality map printing, hard copies might be produced at the RMC, at a single national center, or at state centers.

*Aircraft and ground survey missions that the RMC must perform are listed in Tables 4-9 and 4-12.
**Some in digital form.

6.2.3.1.3 Management, Staffing, Funding

A National Data Center as part of a National Data System performs the central management functions of this EODMS alternative and provides a framework for a system of regional multidisciplinary processing centers. Functions which are handled at the national level include: overall budgeting and priorities; the setting of national standards and specifications for product format; general choice of products and update schedules; combining and aggregating data from the various regions; serving the information needs of the Congress and the President; overall data base administration, including interfaces with the Defense Mapping Agency, other government information systems like the Census and BLS,* and foreign users; some planning of research and development to be carried out at the RMC's; storage of interpreted data sent to Washington which might not include the most detailed, large scale products; and delivery of information to, and consultation with, federal user agencies. In addition the "quick-look" LANDSAT data might be preprocessed and interpreted at a national EODMS facility.

RMC's could use personnel assigned from federal and state mission-oriented agencies. This could occur either in the context of a strong independent EODMS to which programs are transferred intact, or an EODMS governed by a consortium of participating agencies. In the latter case, the RMC might be an umbrella containing regional offices of USDA, USGS, EPA, etc. as well as staff from state user agencies.**

*It's conceivable that a National Data System might wish to incorporate the Census and BLS in its activities.

**Bay St. Louis, Mississippi currently houses several federal agencies concerned with remote sensing which interact with state users.

Assuming the RMC's are part of a unified federal agency, state agencies could participate in its management by serving on the decision-making committee of the RMC.*

Multi-state regional agencies could also play a role in connection with the operation of regional centers. Organizations such as the Appalachian Regional Commission, the Ozarks Regional Commission, the Pacific Northwest Commission, and the Federation of Rocky Mountain States can serve as a cutting edge of innovation in the geographic regions in which they are authorized to function.

Within the constraints of national standards, the RMC's are free to set their own priorities, in accordance with the character of the region. The Great Lakes region has a different menu of data needs and priority products than the Rocky Mountain or Great Plains regions. The RMC's could also experiment with alternative processing methods on an operational basis,** which might reduce the risks of innovation compared with carrying out such activity on a national level.

Funding for a National Data System with Regional Multidisciplinary Centers will probably have to come primarily from the federal government in a manner similar to that for System B. The private sector role in such a system would be limited to providing supporting services under contract to the regional centers or the national agency.

6.2.3.2 Evaluation of System C

6.2.3.2.1 Capacity and Economics

The operation of regional processing centers is unlikely to involve great additional costs as compared to national processing. According to our calculations, a regional center producing the priority

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*Citizen Advisory Councils may be desirable as well.

**This implies that money will be available for R & D.

products from 80 meter LANDSAT data for the five-state region would use roughly the capacity of a Univac 1110 while a national center would exceed that capacity by several times.* A regional center should also keep the most advanced plotting devices and other hardware fully occupied. There would presently appear to be no great economies of scale achievable by a national center compared with regional centers (see Chapter 4). However, if special digital logic or array processors can be applied to implement key algorithms an order of magnitude faster than the best commercially available, third-generation, general purpose computers, this argument loses some of its validity. On the other hand, improvements in sensor resolution beyond LANDSAT Follow-on can have an opposite effect by increasing the data rate.

Calculations in Chapter 4 indicate that there is a sizeable cost advantage for a system in which all the priority products are produced at multidisciplinary centers compared with scattering the production across national disciplinary centers. This advantage arises because of overlaps in the data and techniques required to produce the products and is evident upon comparing single product production costs (Section 4.2) with costs for producing the same products in a multidisciplinary system (Section 4.4).

6.2.3.2.2 Responsiveness and Flexibility

This alternative retains the advantages of multidisciplinary

*If 4-band, 80 meter resolution LANDSAT data were used, we estimate that a Univac 1110 would be utilized about 40% of the time in producing what we have termed the "basis" products for the five-state region. The Univac 1110 is roughly 14 times as fast as the IBM 360/67 and costs about twice as much per hour. If 4-band, 30 meter resolution LANDSAT Follow-on data are used, a CDC 7600 would be utilized about 40% of the time in producing the "basis" products. The CDC 7600 is roughly eight times as fast as the Univac 1110 and costs about twice as much per hour.

processing enumerated previously: low redundancy; sharing of inputs, files, hardware, software, and staff; sharing of administrative support; and ability to shift resources readily among products according to seasonal rhythms, special product requests, and changing information requirements.

Locating the interpretation centers closer to the area being observed allows easier access to ground truth and knowledge of local features, and also allows active participation by representatives of state and local users in EODMS decision making. System performance can be thereby improved in accuracy, timeliness, and suitability of products. A separate center for each region will allow each RMC to emphasize products suited to the character of its region. Another possible advantage of multiple centers is the fact that research and experimentation can be distributed among the regions, with some serving as controls, if adequate funding is available.

6.2.3.2.3 Interfacing

If the national headquarters of the regionally based EODMS is a single agency as in System B, all the advantages of central administration are preserved. These include: a managerial overview of all information gathering and interpretation; the ability to interface with the national executive and legislative branches*, other data bases, and foreign users; overview of all public data needs; and, consequently, the capability to adapt the system quickly to evolving technology and changing data needs.

A primary purpose of establishing regional processing centers is to provide better connections across the gap which now exists

*Also, the judicial branch when natural resources information proves relevant in legal proceedings.

between current LANDSAT products and state agency data needs. Interfaces between state, federal, local and regional agencies have already been established to varying degrees in connection with current mission-oriented activities. New interfaces will need to be worked out in connection with multidisciplinary regional centers if this system is to function well.

6.2.3.2.4 Implementation and Impacts

It seem likely that the creation of a National Data System would cause considerable concern because of the potential negative impacts of centralization of large amounts of information, even though no collection and dissemination of data on individuals is contemplated. We base this belief upon the public concern that arose in connection with the proposal of a FEDNET system in the early 1970's. A national system limited to only natural resources information, System B, might prove more politically feasible. If this major difference in the two concepts is set aside for the moment, implementation should be similar to that described previously under the Natural Resources Information System. Differences could be that regionally based centers will require more geographic shifting of personnel during start-up, but less travel when operational, than would be the case with one national processing center.

A strategy for implementation might involve delivering a fixed menu of priority products on a regular basis as an initial phase of systems operation. The system could then expand to meet the demand for special products as it evolves.

Regional centers might be established by analyzing the locations and patterns of existing disciplinary mission-agency centers and then

choosing sites to minimize expense and provide a maximum of service. Several of the mission-oriented agencies have centers with computers which provide services to a given geographic region and, in some instances, interagency cooperation takes place. Creation of multi-disciplinary regional centers is a political undertaking which will require sensitivity and skill in carrying out. A major independent study of the optimal location, scope of services, staffing, etc. of multidisciplinary regional processing centers needs to be performed if implementation of this alternative is contemplated.

6.2.3.3 Variations on System C

System C can be further decentralized by adding state centers in large, populous states, operated under state auspices or jointly run by state governments and the federal EODMS. State centers could perform visual interpretation of high resolution data, since they are better situated than regional centers to use knowledge of local features. The RMCs could concentrate on digital, automatic interpretation of satellite and high-altitude data. If such state centers are established (this may vary from state to state within a region), they could also perform state user center functions discussed in Section 6.2.1.3. EODMS would have to retain some control to assure that ground truth and aircraft data are available as needed to produce products. Although this variation might entail additional expense, it might serve a useful political purpose by giving states a stake in the larger system and not cutting off initiatives they now have underway.

Another variation involves placing the regional multidisciplinary concept under the auspices of an interagency council. Regional centers could be established to produce only new product types at first, and

only after they have proved themselves would responsibility for existing products be transferred to the RMC's. Alternatively, if RMC's are established as regional offices staffed by representatives of the various mission-oriented agencies, they might be started with existing products. This would gradually be modified and new products added, to take advantage of the interdisciplinary context.

6.2.4 Defining the Private Sector Role

This section explores how some or all EODMS functions could be performed under private auspices. We consider first a Congressionally-chartered private INFOSAT Corporation (System D) which performs most EODMS functions for users in the private as well as public sectors. Then we consider two variations: 1) a system in which a version of INFOSAT serves private users, paralleling a public EODMS for public users and 2) a federally guided system in which the private sector plays a role.

It should be pointed out that a major focus of this study is on data needs at the state agency level. The priority products developed in Chapter 3 reflect this orientation. The system alternatives being considered in this chapter are directed towards delivery of these priority products to state-level and other non-federal public users. In this section, we examine several variations for involving the private sector in this process but we also expand the scope of our inquiry to consider how products might be delivered to the private sector.*

*The public sector data needs embodied in the priority products emphasize comprehensive and detailed information over timeliness, with typical priority product up-date cycles being a year or longer. However, many private users would be willing to sacrifice either detail or breadth of coverage for improved timeliness. For example, agricultural users might want detailed information for the counties they occupy, or comprehensive data aggregated over the entire market, and would not care on (continued on next page)

6.2.4.1 A Congressionally-Chartered System Under Private Control: INFOSAT (System D)

A Congressionally-chartered private corporation, INFOSAT, can be envisioned to operate space systems in the Earth observation field, as a regulated utility analogous to COMSAT in the space telecommunications field (see Figure 6-2D). Like COMSAT, INFOSAT would be a profit-making corporation, with start-up financing appropriated by Congress, and with public representatives on the board of directors.

6.2.4.1.1 System Characteristics

Scope of Data. Input data is primarily from satellite and high-altitude platforms, although sampling and checking require some ground truth and low and medium-altitude aircraft inputs.

Character and Configuration. INFOSAT has the capability to deliver interpreted products to all users, and is therefore multidisciplinary, as seen from outside. Internally, INFOSAT could choose to interpret at disciplinary or multidisciplinary centers as it sees fit. It might choose to establish a center dedicated to agricultural products near a large agricultural market, for example. Economies associated with multidisciplinary centers could be exploited.

The INFOSAT Corporation procures system elements from the private sector, pays NASA for satellite launches and shuttle sorties, contracts for overall system operation and performs data processing.

It either owns aircraft or contracts for aerial photography as needed. Information flows from a national center to regional INFOSAT centers. The national center performs some preprocessing and also has

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which plot a farmer in the next state is growing soybeans. Timeliness is important if the private user is to be aided in decisions such as whether to add fertilizer, what irrigation schedule to pursue, and so forth. It also can be important in public sector decisions. Other private users may value comprehensiveness above timeliness, such as for mineral exploration.

"quick-look" capability which is likely to be of interest to private sector users. These centers pay for the information supplied and can in turn sell products including photo-interpretation and digital-interpretation services at regulated rates.

Management, Staffing, Funding. The INFOSAT Corporation would draw its staff from existing private sector organizations, from government and from universities. The INFOSAT system pricing structure would need to be such that, although regulated, the system could operate at a profit.

6.2.4.1.2 Evaluation

Capacity and Economics. A question which arises with regard to INFOSAT is whether a private corporation, even with a Congressional charter and mandate, would have the incentives needed to produce the full range of priority products for public sector users. Furthermore, some of the information products now on the priority products list, such as topographic maps, would not be produced by INFOSAT unless many functions now performed by government agencies are turned over to the private corporation. Difficulties might therefore arise in coordinating fully the acquisition of ground truth and aircraft data, giving rise to duplication in data acquisition and processing capability. Finally, INFOSAT could have considerable difficulty in aggregating the non-federal public sector market.

Responsiveness and Flexibility. There is serious question about whether a private sector system, however well managed and regulated, could be sufficiently responsive to the public sector needs which we have identified at the state, local and regional level. The analogy with COMSAT breaks down here because most customers of domestic tele-communication satellite systems are in the private sector and the primary

focus of our study is on state, regional and local public sector users.

Implementation and Impacts. The INFOSAT Corporation could be financed initially with congressionally appropriated funds and later by sale of stock as markets for its products and services develop. The corporation could be the sole federally created and regulated corporation authorized to operate space systems in the Earth observation field. There initially was some precedent for such a development in the commercial telecommunications area. COMSAT was established by Congress in the 1960s and initially, government policy towards domestic satellite telecommunications was oriented toward making COMSAT a regulated monopoly. However, this policy has been replaced by one of "limited entry" of a small number of competing companies into the domestic commercial satellite communications field.

The entry of a private entity into the public sector information field on the scale implied by INFOSAT would signal a major shift in government policy regarding such activity (see Chapter 5). Several considerations would appear to make such a shift unlikely. First, it is difficult to see how INFOSAT could operate at a profit and serve public sector users at affordable costs without major government subsidy. A further problem with a private system which would interpret imagery as well as acquire it is the risk of conflict of interest. Some information in the system might be utilized to the competitive advantage of corporations in which INFOSAT directors have an interest over other corporations or in conflict with government agencies. Currently, government-developed agricultural crop forecasts are carefully managed by USDA to insure that premature disclosure gives no one an unfair advantage.

The principal advantage of INFOSAT is that the profit motive would encourage active development of the potential market for remotely sensed information. However, the policy issues discussed in Chapter 5 and the traditional involvement of government in certain elements of the information field would seem to cast doubt upon the wisdom and practicality of putting all public and private sector activity under one private corporation. In the rest of this section, we consider two alternative approaches to private sector involvement which avoid some of these problems.

6.2.4.2 Variation I on System D: Parallel Systems for Public and Private Sectors

We consider parallel systems for public and private users as a variation of the privately controlled System D. A private corporation, INFOSAT II, is restricted to serving the private sector while public data needs are served by a public EODMS organized according to one of the previous models. This arrangement is similar to what has evolved in the area of weather prediction where the predominantly public sector weather service is paralleled by private sector operations. The priority products defined in Chapter 3 would be delivered by the public sector system.

The private sector operation would evolve a set of private sector priority products based on the private marketplace. Preprocessing of satellite data need only be done once, for all users. A public EODMS facility (NDPF, for example) could perform this function without greatly affecting the other levels in the system. Sales of data to the private sector might be a source of government revenue. Since continued rapid technological change in this field can be anticipated,

government control of preprocessing would allow system-wide planning for future evolution of the system. INFOSAT II would obtain preprocessed data for a fee which it would interpret and market in timely fashion to private sector users.*

One remaining problem would be that dissemination of information on the basis of ability to pay would favor larger enterprises which can afford to pay for subsequent interpretation. The favoring of large enterprises may be intrinsic to the nature of the technology, unless pricing policy is set to provide some equalization. There is a strong tradition in the U.S. of providing support for small business and a newer tradition of protecting the "public interest" as well.

6.2.4.3 Variation II on System D: A Federally Guided System in Which the Private Sector plays a Major Role

This variation is an alternative under public auspices in which the private sector becomes heavily involved in carrying out many of the system functions, including interpretation. The federal role includes overall system management, acquisition of satellite and high-altitude aircraft data, some preprocessing and major funding. Private industry plays an important role as a contractor to EODMS to produce public sector priority products.** Contracts for operation of production facilities are let on a long-term, competitive basis to ensure some return for the private sector producer of public products and, in effect, to regulate the costs of those products. Other roles for the

*It should be noted that this may very well evolve under the current LANDSAT experimental system, with the private sector being the major user of EROS data. However, present trends do not favor the evolution of the public side of the system to serve state, local and regional users.
**Currently, the Government Printing Office contracts with private companies for its printing requirements.

private sector within a federally guided EODMS may be foreseen in data communications and storage.

There are some problems associated with contracting with private industry for priority product production. Some of these products are now produced by public agencies. Problems associated with premature release of agricultural information were mentioned in Section 6.2.4.1.2. Thus, it may be desirable to carefully delimit the role of private sector contractors to areas which are not sensitive and which do not have a long tradition of public sector involvement.

Currently, low-altitude photography is acquired by private contractors, although some states have their own capability. The private sector role in a federally-guided EODMS would retain this involvement although they would be hired by EODMS rather than by separate user agencies. Expensive duplication and overlaps in data gathering would be avoided by multi-purpose flights regularly scheduled by the central administration.

Private industry is currently active or potentially so in several other capacities. Research and development of sensors, hardware and software for image interpretation and display, and data transmission can be done by private contractors under government contract. The task of rationalizing government spatial information systems, establishing guidelines for interfacing, systematic indexing, assignment of storage locations, etc. may utilize private consultants. A public system would also need to make major equipment purchases from the private sector.

Interpretation of remotely sensed data into finished products for

private users, along with marketing and dissemination to users may be performed by private enterprise. Indeed, there has been activity in this direction already. For example, the Earth Satellite Corporation of Washington, D.C. offers a service called Cropcast*, which it states can provide timely crop production forecasts to its customers. (6-7) Other firms providing such services using raw data obtained from satellites, other public data, and perhaps data collected independently are likely to emerge naturally.

It should be noted that Variation II of System D could be made to resemble any of our public sector alternatives (System A, B, or C). We have included it in this section because of its specific emphasis on the private sector role.

*Cropcast currently uses weather data in its forecasts but does not normally use LANDSAT data because it is slow and infrequent. (6-7)

6.3 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

One objective of this project is to outline several EODMS system alternatives and to indicate which are deemed worthy of more detailed future system synthesis and assessment. The assumptions and constraints (Section 6.1.3) under which this analysis has been carried out should be kept in mind. In particular, we have required that the system deliver a broad spectrum of interpreted information products to state, local and regional public sector users.

Table 6-2 on page 198 summarizes the principal features and evaluations of the four EODMS system alternatives. In this section we briefly draw conclusions about the four alternatives. We then describe two somewhat modified systems which seem promising for future consideration. The chapter concludes with recommendations for future research.

6.3.1 Conclusions Concerning System Alternatives

6.3.1.1 An Evolutionary System Based on Present Institutions (System A)

This predominantly public sector system builds on current federal agency capability with processing carried out at national disciplinary centers. We believe that certain features of this system are worthy of further study. In particular, placing system management under an Interagency Council with representatives of existing agencies corresponds more closely to current reality than the other alternatives. Interagency rivalry would have to be overcome and cooperation fostered but bringing this about may be less difficult than creating a new agency. Agencies such as NASA, USGS and USDA are actively seeking greater involvement as well as improvements in the current "experimental" arrangements. The inclusion of state agency representatives in such a Council would greatly improve prospects that System A would prove responsive to non-federal public sector needs.

However, national disciplinary centers appear to have more disadvantages than advantages. Such an arrangement would be costly and might result in duplication of effort due to lack of coordination. A state user center variation in which interpetation is divided between the national centers and state centers could make System A more politically acceptable to users but may prove too costly for smaller states to implement.

6.3.1.2 A Natural Resources Information System With Interpretation at a National Center (System B)

This predominantly public sector system alternative appears to offer savings in operating costs and elimination of duplication by putting all natural resources information activity under the auspices of a new agency. However, the establishment of such an agency as a new arm of the Executive Branch of government or through major government reorganization is a major political act which could involve high costs and slow start-up. One such reorganization was proposed in the early 1970's but the idea faded. We believe that the time may be right for such reorganization and that the idea of a natural resources information system should receive further, detailed consideration.

Production of priority products at a multidisciplinary national center would appear to offer economies over processing at several national centers operated by disciplinary (mission-oriented) agencies. However, we believe that the economic advantages of national processing over regional processing are not sufficient, given current commercially available computers and the importance of non-computer processing costs, to overcome its disadvantages such as excessive centralization, and remoteness from the local terrain, ground truth, and users. Regional and large-state branches of a national system could alleviate this problem, particularly if users are heavily involved.

6.3.1.3 A National Data System With Interpretation at Region Centers (System C)

This EODMS alternative carries the Natural Resources Information System concept of System B one step further by including all government-collected or supported data within this predominantly public sector system, using data or information as the theme of a new government agency. However, interpretation and product production are carried out in regional multidisciplinary centers rather than one national center.

Under National Data System management, an EODMS should retain the advantages of cost-efficient operation which apply under System B management. However, we believe that the idea of centralization of both natural resource and socioeconomic data and information products within one federal agency is likely to be politically unacceptable due to fears of excessive government controls and intrusion, even though collection of data on individuals is not contemplated. We base this conclusion on the negative public and congressional reaction to the "FEDNET" idea several years ago which, although different from what is proposed in System C, had a similar element of consolidating data from several federal agencies within one central agency.

The concept of regional multidisciplinary processing centers appears to be very attractive and to warrant detailed future investigation. A region the size of our five-state study region seems about the right size on economic and technical grounds. Also, state agency users should be able to have more say in how a regional center is run than for a national center. Individual states of sufficient size and budget may be able to operate their own multidisciplinary centers. Alternatively, some states may continue doing limited visual photo-interpretation while the regional centers handle the digital processing.

6.3.1.4 A System With Private Sector Control (System D)

We have explored a predominantly private sector system, the "INFOSAT"

Corporation, in which a Congressionally-chartered utility delivers priority products to both public and private sector users. A major problem we see with this arrangement is that, in addition to probably requiring major government subsidy, it would be delivering information products which are now provided by public sector agencies. In some instances, as with USDA crop forecasts, the release of this information is carefully managed to insure no advantages to any private group.

The Space Applications Board, in a 1975 report stated that they believe a Congressionally chartered Space Applications Corporation (or Corporations) will come into being as the management mechanism in the Earth observation applications field, but not for at least three to five years.(6-3) While this may very well prove to be the case, we do not believe that such a mechanism will be as responsive to the needs of the state, local and regional users who have been the principal focus of this study as a publicly-controlled system. COMSAT does not seem an appropriate model because the latter organization functions domestically as one of several entries into the telecommunications field, oriented almost totally to private sector users.

Two variations for private sector involvement seem more promising. First, it is possible that one or more private sector systems will emerge to service private users in parallel with a public sector system. Some evidence of such private sector activity is beginning to appear. Second, the private sector could play a major role in any of the public sector systems by providing certain services under long-term contract to government agencies, perhaps including interpretation.

6.3.2 System Alternatives for Future Detailed Synthesis, Design and Assessment

Based upon our analysis of the four system alternatives, we conclude

that two public system concepts seem promising for future study. The first is a modified System A, an evolutionary system based on present institutions in which an interagency council involving NASA, USGS, USDA and other federal agencies pools their resources to deliver priority information products with a minimum of duplication to state, local and regional users. Although the structure of such a system would seem to favor what we have described as "disciplinary" (i.e. existing mission-oriented agency) approaches, we believe it important that ways be found to involve more than one agency in the oepration of processing centers. We also believe that a substantial amount of activity should be carried out at the regional or large-state level.

The second promising alternative, a hybrid of Systems B and C, involves the creation of a natural resources information system with processing at regional and large-state multidisciplinary centers. In several respects, this alternative appers the most attractive to us. However, it requires the creation of a new government agency, perhaps within an existing department, for implementation. We believe that such a step may yield substantial benefits and should receive serious consideration.

We do not believe that a system under private sector control, System D, is likely to be an appropriate mechanism for providing the services to state, local and regional agencies which have been the central focus of our study. However, we do believe that many opportunities for private sector business will be created by developing the kind of public sector system we envision.

6.3.3 Recommendations for Future Research

Detailed systems synthesis, design and assessment studies should be carried out of 1) a natural resources information system with interpretation at regional centers (Hybrid System B-C), and 2) an evolutionary system

based on present institutions (Modified System A) in close cooperation with agencies which might be involved in such systems. Among the elements of such a study which should receive careful attention are:

- Optimal location, size, technical capability and management of regional multidisciplinary centers.
- Potential role of time-sharing and computer-communication networks in data storage and dissemination.
- Economics of high-quality map printing technology.
- Detailed engineering design of the systems to identify cost performance tradeoffs.
- Variation of system cost and utility with changes in product menu.
- Government pricing policy pertaining to priority product production.
- Costs and benefits of each system, with particular attention paid to information product accuracy and timeliness requirements, and to an awareness of the difficulties involved in such studies.
- Strategies for implementation, including the role of cooperative state, federal and regional activity as preparation for operational system involvement; and time phasing of product production, equipment acquisition, and necessary enabling legislation.
- The role of the private sector in a public sector EODMS.
- Detailed consideration of the likely consequences of EODMS implementation, and development of policies to cope with these consequences.

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